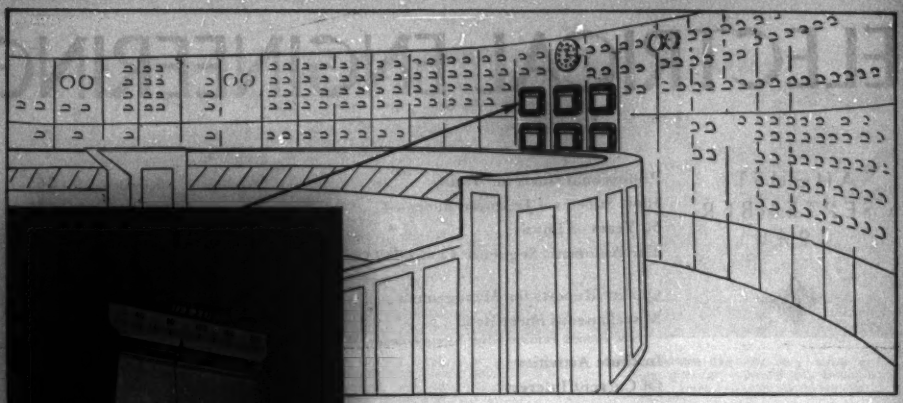
ELECTRICAL ENGINEERING

AUGUST–SEPTEMBER 1946

With this August–September issue, mailing dates of Electrical Engineering are advanced one month in order that the majority of readers may receive copies by the first of the month of issue. Details are given on page 408.

AIEE GREAT LAKES DISTRICT MEETING, INDIANAPOLIS, IND., OCTOBER 9–11, 1946



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HIGHLIGHTS.....

August–September Issue. The double dateline on *Electrical Engineering* this month does not mean that an issue is being skipped, but is simply a device for rearranging the production schedule to insure early mailing of copies (*page 408*).

Summer Convention. Setting a new attendance record for recent years with a registration of 1,351, the 1946 AIEE summer convention was held in Detroit, Mich. An unusually heavy technical program marked this year's convention as well as a series of entertainment features highlighted by contests for the Mershon and Lee golfing trophies. This is the 61st annual summer convention of the Institute and the third time it has convened in Detroit (*pages 396–7*).

Sections. One of the outstanding features of the recent AIEE summer convention was a series of six conferences on Section activities arranged by the Sections committee. The conferences, whose popularity was attested by a very gratifying attendance, included an officers and delegates session which was addressed by both President Wickenden and President-Elect Housley (*pages 398–407*). Also included were three separate but parallel conferences which were held to permit discussion of common problems and exchange of experiences among Sections of similar size. The three sessions were conducted for the larger, intermediate, and smaller Sections (*pages 402–03*).

Professional Goals. "The essence of modernity is that progress no longer waits on genius; instead we have learned to put our faith in the organized efforts of ordinary men." In the presidential address delivered at the recent AIEE summer convention in Detroit, Mich., President Wickenden added his voice to the plea for national unity among engineers, one of the goals toward which Doctor Wickenden and his fellow AIEE officers have been working during the past year (*pages 365–9*).

Automatic Control Systems. Technical literature thus far has not given very adequate coverage to that class of servomechanism in which the components in the direct circuit are paralleled by components in a feed-back circuit. Treatment of a complex dynamic system is difficult on the basis of classical mathematics. However, an analysis is not only of value in giving a quantitatively approximate idea of the correct approach to a problem, but, if it includes experimental data on the performance of the major components, it can set up exact specifications for the design of the remaining circuits (*Transactions pages 521–9*). For an analysis of automatic control systems in general, the frequency response approach or the transient response approach may be used. Of the two, the frequency analysis provides information equivalent to the transient analysis, but with less calculation and more easily interpretable results (*Transactions pages 539–46*).

Physics' Half Century. Evolving over a period of 50 years from the periphery to the very center of the scientific circle, the United States today boasts more than three-fifths of the world's physics' activity—a far cry from an era when Benjamin Franklin and Joseph Henry were the only American physicists of note. Much of the current activity, of course, is the direct result of the recent war which stimulated scientific research in America but greatly curtailed it in Europe (*pages 378–83*).

Japanese Radar. Because "Our Emperor directed us to tell you everything," the Japanese people were unexpectedly cooperative in revealing to Allied officers what they could of Japan's technical activities during the war. What has been learned about their radar developments is reported in a 2-part article, beginning in this issue, by an ex-operations analyst who was assigned, after the fall of Japan, to study all phases of Japanese electronics and radar (*pages 370–7*).

Automatic Calculator. In 1642 the foundation for almost all modern mechanical calculating machines was laid when Blaise Pascal built the first mechanical adding machine incorporating the use of rotating wheels and providing for carry. One of the latest devices in this field, the automatic sequence controlled calculator developed by Harvard University and International Business Machines Corporation, is described in a 3-part article beginning in this issue (*pages 384–91*).

Quality Reports. The successful employment of quality reports in an increasing number of industrial concerns recommends an even more general usage although, in many cases, the installation of a quality control system will have to be preceded by the conversion of a hostile management. The reports themselves may be presented in any of several ways, the choice being determined by conditions in the plant in question (*pages 391–3*).

Radar Range. Most radar sets in use during the recent war functioned by transmitting a pulse and measuring the time necessary for the signal to reach the target and the echo to return. Under these conditions the most interesting problem which arises is the question of how much power must be transmitted so that the echo will be of sufficient strength to be detected satisfactorily by the radar receiver. In the case of microwave equipment, and the consequent line-of-sight transmission paths, the problem can be solved by geometric means (*Transactions pages 585–8*).

Ladder Networks. When using a uniform ladder network (in the 4-terminal sense) to simulate a smooth transmission line, it is agreed that under some conditions a mid-shunt termination gives the best results while with other terminal conditions the midseries arrangement is superior. With the understanding that the network retain its 4-terminal identity, can an intermediate termination be found which will give a uniformly good approximation for all conditions (*Transactions pages 530–6*)?

Dangerous Currents. Current and *not* voltage, in spite of prevailing misconceptions on that point, is the proper criterion of electric shock intensity. The effect of the shock on the victim will differ depending on the part of the body through which the current passes. The value of other factors, such as body and contact resistances or elapsed time between occurrence of the accident, rescue, and resuscitation usually can be estimated only roughly (*Transactions pages 579–85*).

Preserving Pole Woods. As a result of the backlog of pole requirements built up during the war and of today's labor shortages, it has become difficult to obtain a sufficient supply of the more extensively used pole woods. In an effort to solve the problem the American Standards Association has issued specifications covering various previously unrecognized conifers which may be given preservative treatments and used as substitutes (*Transactions pages 549–54*).

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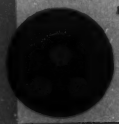

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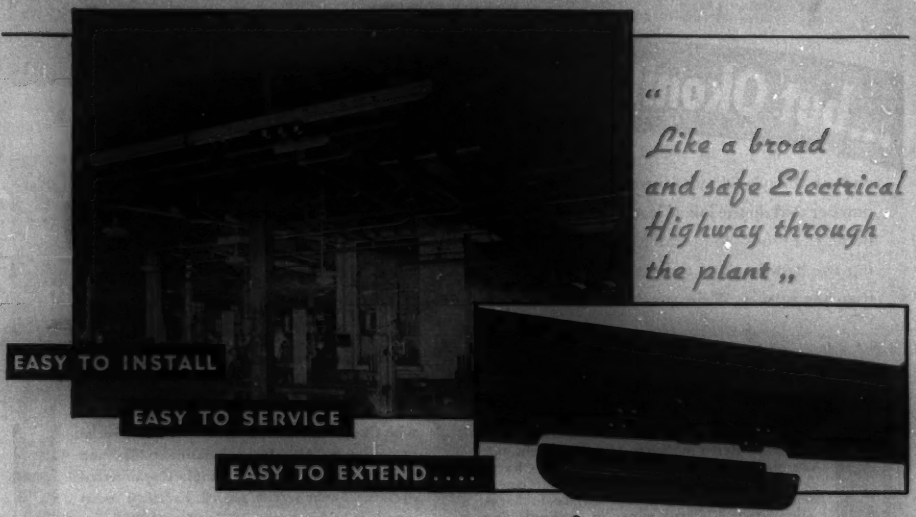

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Then Radar arrived. The silicon crystal came into its own, and found application in long-distance microwave Radar. Working with American and British colleagues, the Laboratories rapidly perfected a unit which the Western Electric Company produced in thousands. It became the standard microwave detector.

Crystal detectors are destined to play a big role in electric circuits of the future. They will have an important part in Bell System microwave radio relay systems. In various forms, they may reappear in radio sets. Here again Bell Laboratories' research has furthered the communication art.

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Not until man learned to organize his efforts was he able to attain mastery over nature to any significant degree and so, as a result, most of his accomplishments have been confined to the past three centuries. With this example before him the engineer, also, has become interested in organization, but only in his particular specialized field. If engineers are to assume a role of leadership in the industrial world there must be a new unity among members of the profession as a whole, a unity which the Institute, as largest of the national engineering bodies, has a special obligation to cultivate.

WHAT WE CALL western civilization is a social order based on science and technology, the product of three centuries of the most highly organized effort of the human mind. Man has inhabited the earth for perhaps a million years, but within living memory he has gained in mastery over nature more than in all the millenniums which went before. Is the secret of this triumph some element of genius peculiar to the modern mind? It would be flattering to our pride to think so, but probably untrue. Geniuses of the first magnitude have been rare among the moderns. Who within these three centuries dares to measure his stature with a Moses, a Homer, an Alexander, a Plato, a Jesus, a Michelangelo, or a Shakespeare? The essence of modernity is that progress no longer waits on genius; instead we have learned to put our faith in the organized efforts of ordinary men.

Science is as old as the human race, but its effective organization is new. Ancient science, like placer mining, was largely a pursuit of solitary prospectors. Nuggets of truth were found, but often lost again, and the total wealth of knowledge increased slowly. Modern man began to transform his world when he began to mine the hidden veins of knowledge systematically. Science began to be powerful when it began to be cumulative, when observers began to preserve detailed records and to organize co-operating groups in order to pool their experiences and submit them to critical scrutiny. Effective science began when men made the winning of knowledge their distinctive function or profession, when specialists began to break it up into ever smaller fragments in order to pursue it more intensively. To this idea of progress that does not wait on some lucky break or rare stroke of genius, but instead is achieved through the cumulative, organized efforts of ordinary men, the engineer has contributed brilliantly. It is still his major responsibility.

Engineering and architecture stem from common origins, now lost in antiquity. Their separation into distinct professions, already well advanced in France and Holland, appeared in Great Britain as one of the later fruits of industrial revolution. It marked the transition from a highly individual art practiced by a few craftsmen, whose knowledge was largely the fruit of personal observation and experience, to a profession with advisory functions as well as individual skills, inspired by common ideals and regulated by the accumulated knowledge of many observers and practitioners.

Essential substance of the presidential address delivered at the AIEE summer convention, Detroit, Mich., June 24–28, 1946.

FIRST ENGINEERING ORGANIZATION

The first impetus to organization sprang from an educational need. In a period when the British educational system ignored science and made no provision for technical and professional training, and when no established body of practitioners existed to afford an orderly apprenticeship, it was a formidable matter to enter upon an engineering career. In the account of the founding of the Institution of Civil Engineers in London we read:

> "It was toward the end of the year 1817 that a few gentlemen, then beginning life, impressed by what they themselves felt were the difficulties young men had to contend with in gaining the knowledge requisite for the diversified practice of engineering, resolved to form themselves into a society."

The eight founders, who were principally builders of machinery, began their deliberations by discussing the familiar parallel motion of Bolton and Watt. Clearly, this group had no thought of differentiating a distinct branch of engineering concerned with permanent structures and public works when they chose the title "Civil Engineers." The special significance we now associate with that title appears to have grown up around certain personalities and their professional interests, especially Thomas Telford, who became, by invitation, the first president of the new Institution and strongly influenced its character. Telford had been a stone mason, and his personal fame rested on great works of construction.

Telford at once recognized the distinction between the learned academies which had been instituted by the

governments in continental Europe and this more individualistic expression of British ideals. He reminded his fellow members that the very existence and standing of the Institution must depend on their conduct and exertions, that "talents and respectability are preferable to numbers and that from too easy and promiscuous admission, unavoidable and not infrequently incurable inconveniences perplex most societies." The functions of a selective professional guild, thus voluntarily assumed, were confirmed by royal charter in 1829 and always have been prized jealously among British engineers.

The famous definition of civil engineering as the "art of directing the great sources of power in nature for the use and convenience of man" framed by Thomas Tredgold as the basis of this royal charter, pointed to a unified rather than a differentiated profession. Strong forces of individualism, however, continued at work and prompted the establishment of the Institution of Mechanical Engineers as a separate body. By 1847, the dominant interest of the Institution of Civil Engineers in fixed construction had grown more pronounced. George Stevenson, self-taught genius and father of the locomotive, found the atmosphere of the older society uncongenial and himself possibly unwelcome, so lent his influence to the formation of a new society, of which he became the first president with his son Robert succeeding him. Apparently there was less caste feeling and more zeal for innovation in this new body, which stated as its objects,

"To promote the science and practice of Mechanical Engineering and all branches of mechanical construction and to give an impulse to inventions likely to be useful to members of the Institution and to the community at large, and also to enable mechanical engineers to meet and to correspond and to facilitate the interchange of ideas respecting improvements in various branches of mechanical science and the publication and communication of information on such subjects."

By 1871, when the Society of Telegraph Engineers, later to become the Institution of Electrical Engineers, was organized, the eight notable founders, headed by Lord Kelvin, doubtless considered the creation of a separate and specialized institution as natural and inevitable.

So much for British example and influence transmitted to America. To the highly individualistic traditions of the industrial revolution there were now added equally individualistic influences of a frontier economy. Scattered personnel made the initial organization of the profession in America difficult. The first attempt in 1839 failed, and when the American Society of Civil Engineers and Architects finally was established in 1852 its activities were short lived, lapsing from 1855 to 1867, when the society was revived and reorganized as the American Society of Civil Engineers. While apparently planned as a national and inclusive professional body, the functions now distinctive to civil engineering were emphasized strongly in its early leadership and activities. The mineral and machine industries, which expanded greatly under the impetus of the Civil War appear to have had little place in its interests.

EDUCATION AS AN IMPETUS

At this time a new impetus toward specialization entered into professional life, through the establishment of a school of mines at Columbia University in 1864 and the introduction of a curriculum in mechanical engineering at the Massachusetts Institute of Technology in 1865. To these pioneer efforts the Morrill Act to aid the establishment of colleges of the mechanic arts soon gave an added impetus. Professors, whose interests tended to be individualistic, and the whole scheme of higher learning based on intense specialization borrowed from Germany, soon began to have a pronounced influence on the budding life of the profession. These forces can be traced in the organization of the American Institute of Mining Engineers in 1871, and especially in the American Society of Mechanical Engineers in 1880. In the latter, such men as Professors John Sweet and R. H. Thurston found an outlet for talents which might not have been afforded by a long established organization. The American Institute of Electrical Engineers derived much of its organizing impetus from the telegraph industry and throughout its 62 years has had much more intimate association with corporate industry than with independent practice.

Until fairly recent years almost every force of tradition and circumstance has worked toward a progressive fragmentation of the larger profession. The goals of organized effort have been chiefly the increase and diffusion of knowledge, the exchange of experience, the codification of practice, and the standardization of usage, and to all of these specialization has lent a powerful aid. It was usually easier for some dominant personality to gather a coterie of enthusiasts about some new specialty than to penetrate the barriers of inertia or vested interest in organizations long established. Loss of solidarity was seemingly a secondary concern; the profession-at-large was conscious of a common heritage of scientific knowledge and proud of its progress in practical skills. Not much else united it or seemed to matter.

The current Directory of Scientific and Technical Societies published by the National Research Council lists 1,259 such organizations in the United States and 143 in Canada. Included in the 1,259 total are 49 local, 40 regional, and 29 national engineering organizations, without national integration and with no end of proliferation in sight. Since the turn of the century, however, a slowly increasing trend toward unification has been apparent. Symptoms of unrest appeared as engineers came to realize that older and more closely integrated professions somewhat overshadowed them in prestige, that their own specialized forms of organization afforded little protection to their legal and economic status, that their influence on public policies and meas-

ures was small in proportion to their numbers and functions, that the revolutionary consequences of their activities carried with them a corresponding obligation to direct them to socially desirable ends, and that both the economic and military security of the nation rested largely upon their shoulders. Few of these concerns had been in the minds of the founding fathers or had found expression in stated aims of existing societies.

Among our leaders were a few men of vision like Charles F. Scott, who saw that existing organizations must come to know each other better and to work together more intimately if any foundation for future unity ever was to be laid. His influence on Andrew Carnegie, which bore fruit in the establishment of the United Engineering Societies and the erection of a common home for the four Founder Societies, must be ranked as a major act of statesmanship. Protest as well as vision was working toward unity. The American Association of Engineers, organized in 1915 with the avowed aim of complete solidarity in matters of status, welfare, compensation standards, and public influence, was, in fact, largely a protest movement on the part of the forgotten men of the profession.

Vision predominated in the establishment of the Federated American Engineering Societies (later the American Engineering Council) in 1920 as the ambitious effort of 36 engineering societies—national, regional, and local—to establish an "embassy of the profession in Washington." Stratospheric in conception and aims, it lacked a supporting base at the grass roots, and ultimately collapsed, just when it was needed most, as the constituent bodies withdrew their financial support.

Meanwhile a movement for professional licensure had been gathering momentum in engineering circles. The guild ideal of professional status maintained through self-established bodies of selective membership failed to satisfy a substantial and increasingly vocal segment of the profession who viewed with some envy the more exclusive status of physicians and lawyers. Doctors long had been licensed by the state as a matter of public protection and lawyers by reason of their public function as officers of the courts. The movement for licensure among engineers, it seems fair to state, while advanced as a measure of public protection, has been pressed primarily as a means of creating and defending a more distinct status for engineers. It is not an isolated movement, but has its counterpart among other groups seeking a similar goal, such as social workers, chemists, and physicists. The establishment of national, state, and local organizations to foster the licensing movement and to police its operations has been a natural and possibly an inevitable concomitant, and now is developing into a positive force for professional unification. The time is not yet at hand for a full appraisal of this movement. The results so far, while almost wholly good, are partial at best and remain far short of the goals announced. Many minor and some major abuses have been eliminated, but positive advances are discerned less easily. The possibilities for a gradual raising of educational and experience qualifications, and for unification on the level of personal status and public responsibility, seem definitely promising.

In the same period functional activities among engineers also have been working toward unity. The engineering educators, who individually have done much to foster specialized societies, at the same time have built up a powerful force for unification through their own national organization, recently reorganized and renamed as the American Society for Engineering Education. Engineers' Council for Professional Development, while yet to gain full momentum, has given an impressive demonstration of its possibilities in the accreditation of college curricula and in correlating them with licensure practices; also impressive is its contribution to a more reliable means of preselection for engineering students. The standardization movement, taking shape in the American Standards Association, has become a unifying force working across the boundaries of specialized fields and organizations.

More recently there has been a rapid multiplication at the roots of engineers' joint councils, creating the basis of local collaboration as a support for nation-wide collaboration which American Engineering Council lacked. Most recently of all, the Engineers' Joint Council, which has evolved during the past year from an informal conference committee of society executives, has become a potent agency for collaboration among five of our major national societies, and is extending its range of collaboration among other organizations on a task basis. While consciously avoiding any attempt to pre-empt any permanent role for itself, it actively is seeking to stimulate and guide evolution toward unity of effort in public and professional affairs on a high plane commanding the adherence and support of the recognized leaders of the engineering fraternity.

NECESSITY FOR UNITY

As these movements have advanced the cause of unity within the profession, powerful political, economic, and social forces over the continent have worked to make greater unity imperative. One by one the old landmarks of society have been going down, as economic pressure groups have been setting up new ones for their special advantage. Public policy no longer is made by a counting of individual ballots. Dominant groups in manufacturing, transportation, mineral industry, agriculture, and labor are organized solidly and have learned thoroughly the strategy of concentrating their shock troops on the political front. The traditional specialism and individualism of engineering and science are at home ill in this new political-economic world. A new political philosophy has become ascendant, in which agriculture is the protected ward of the state, labor can do no wrong, industry can do no right, and the profes-

sional and intellectual classes are too few and too scattered to count.

The hitherto highly individualistic professions now find themselves threatened on two fronts with loss of identity, as industry on the one hand tends to absorb them into an undifferentiated mass of salaried employees, and as organized labor on the other seeks to force them into regimented ranks of dues-paying card-carrying closed-shop bargaining units, while doing its utmost to destroy all salary differentials between technically skilled groups and those employing routine manual skills.

Engineers need to fortify themselves beyond all doubt, but I must confess to being concerned less about protective measures than constructive ones which may enable engineers to seize their now unprecedented opportunities for leadership in the industrial world. It is the business of the scientist to wrest secrets from nature and that of the engineer to make them useful to man. These roles continue in war and in peace; they do not change with circumstances. They grow in importance as the world's population multiplies (it has doubled in the last century), as the standard of living rises (income standards have risen six-fold since colonial days), as the need for new wealth increases, and as the original stores of natural wealth—what we may call wind-fall wealth—decrease. Civilization is simply a race between progressive exhaustion of nature's treasures and the ability of science and technology to renew and replace them. So far we have been winning the race by drawing upon new deposits, but it must be apparent to all that the period of wind-fall wealth in America daily is drawing nearer its close. This fact invests the dawning era of nuclear energy with special significance. For older and spent countries like Britain its potentialities for good or evil are startling.

But there is yet another role for scientist and engineer, less dramatic but equally critical. It consists in bringing the spirit and service of professional life more fully into the direction of industry. Obviously, some new directing force is needed. The old rule of power, vested in ownership, has broken down. Management's past excesses and blunders arise at every turn to plague it, most of all in the incitement given to labor to demand power without responsibility. The rule of bargaining has broken down, only its legal shadow remains as government intervenes to fix wages and dictate price levels. The rule of political appeasement has broken down, with the pay-off of wartime promises that labor's part was to be all gain and no sacrifice. The rule of labor solidarity has broken down as the nation revolted on the brink of paralysis. And now public authority has broken down, as the President, on the threshold of chaos, began by shaking his fist and ended by shaking his finger.

The doctrine of sacred rights has broken down, the right to do whatever one chooses with one's property, the right to run one's business as one pleases, the right to hire and fire at will, the right to work at will, the right to strike on caprice, and the right to imperil the community and nation to get one's way. The word *sacred*, it appears, has been a shield too lightly seized. Wise old Justice Holmes, in a day when the Supreme Bench commanded higher honor, spoke the brave and simple truth,

> "When the power of either labor or capital is exerted in such a way as to attack the life of the community, those who seek their private ends at such costs are public enemies."

Implicit in the breakdowns recited is the simple truth that there are not two parties to the struggle but four. *Investors* have a stake in it. Industry without capital is inconceivable; men will not save without incentive or risk without hope of gain; and no free government ever has existed apart from free enterprise. Invested wealth cannot strike and survive nor can it walk out on its job at will. Its only worth, except as junk, is in its productivity and there hangs over it at all times, like threat of doom, the spectre of obsolescence. These things should be the measure of its reward, but property rights are relative and not sacred.

Workers, too, have their stake. Men must work not only to live but to maintain their sense of worth. Slaves can be driven by the lash, but free men will not put their hearts into their work when driven by compulsion, haunted by fear, denied the right of association, or frustrated from normal self-expression. What fallacy was discredited more than the supposed economy of low wages or excessive hours of work? Men are entitled to the conditions and rewards of work that will make them most efficient, but this right is relative and not sacred.

Consumers, too, have their stake. Subsistence is possible on a hill-billy farm, but no one can prosper unless customers can buy. Artificial scarcity and inflated prices can bring only transient gains to the few, while abundance at attractive costs benefit every one. Henry Ford's high stroke of genius was in curing the automobile industry of its luxury complex at an early age and at a high wage level. It is not in the general interest that labor alone should receive the entire fruit of scientific advance and technological gain, as it is now demanding, in the face of its own decreased productivity. High wages with high production make eager customers, and the battle against inflation actually is not fought in Washington but upon industry's production lines.

The *public* too has its stake. An unstable economy is a threat of public calamity. Nine-tenths of the world's business is done on credit, and credit is faith in a future where a dollar will be worth at least as much as it is today. If we in the United States have inflation, inevitably we shall lend-lease it to our neighbors, and possibly to the world. If we create an artificially high wage level or scant production we may force our economy back within itself and so dim the hope of recovery for other peoples and make the peace of the world just that much harder to maintain.

The nation at this juncture is sorely in need of leaders who can see its economy and its international interests whole, and not as partisans of labor, or ownership, or agriculture, or geographical units, or political blocs. Industry, likewise, is sorely in need of leaders who can bring reconciliation from within. I believe the hope of finding such leadership lies in the essential quality of trusteeship which is embodied in professional life and service. Among the professions, I believe engineering has a unique contribution to make. Only as we entrust leadership in industry more fully to professional men who acknowledge their responsibility to investors, workers, customers, and the public alike, and whose highest aim is to reconcile and unify these interests for the common good, can there be hope of finding some way out of this crippling strife. If the engineer meets this challenge, he will be the man of destiny.

ADVANTAGES OF THE ENGINEER

The engineer faces this challenge with marked advantages over any possible rivals. He is there on the ground. He already has driven a deep salient of professional interest and spirit into the industrial world. In the electrical, chemical, metallurgical, and automotive world he is already dominant in management. His methods—factual, objective, analytical, experimental, and inventive—are in his favor. His position is a natural bridge between the mechanical and the commercial skills. He starts from an impartial base, with professional canons of integrity, trusteeship, and ethical obligation that rise above the lowlands of partisan expediency. He does not start singlehanded, but has behind him a great organized body to reinforce his standards and ideals.

The essential conflict between labor and industry today is not merely a struggle for rewards, but also a struggle for security. Our fathers found their security in the soil, in years of adversity they returned to the land. Now, when lean years come, the urban and industrialized population has no place to go except to the relief rolls and the insurance office. Our fathers were a land- and property-minded generation; we are a job- and social-security-minded generation. There are tides in the affairs of men, as inevitable as the tides of the sea. Engineers control the tides and prevent them from washing away the shore line; they even harness them and turn them to useful work: but only fools try to sweep them back with a broom.

In today's epic conflict between labor and industry, the engineer has a five-fold part to play. *First*, he must speed the advance of research and the improvement of machines and processes which alone will enable industry to meet its newly imposed obligations to labor, and still earn the profit necessary for its survival. *Second*, he must persuade labor to put its heart back into production. To this end he must devise incentive methods of compensation, set fair standards of output, and convince labor that these incentives, standards, and rules of reckoning are on the level and will work to the general interest. *Third*, he must convince labor that its own interest is served best by keeping the engineer on a professional level, where he can act impartially and independently, rather than by forcing him into the rank and file of union organization. *Fourth*, he must convince the employing world that he is not just a nondescript employee to be ordered around at will and paid the least the traffic will bear, but is actually a professional man exercising high knowledge and skill, under compact with his colleagues to observe an austere ethical code and a high role of trusteeship. *Fifth*, he must strengthen and implement his professional life by organization so that he can act with independence and impartiality and that his voice can be heard effectively on public issues which affect vitally the security and economic welfare of the nation.

The historic diversity of engineering organizations has been exceedingly fruitful. It has contributed magnificently to the gain and diffusion of knowledge, to the interchange of experience, to the testing and codification of practice, and to the standardization of usage. It has encouraged originality and innovation. It has given vigorous new blood a chance at leadership. It has prevented the ossification of vested interests. The Institute, and its sister organizations, are tested tools of progress to be kept tempered and keen. Under no circumstances should they be blunted or discarded in the interest of a merely formal unity. Nevertheless, unity is needed on a level above specialization, to provide the safeguards of professional independence and the instruments of public influence without which the engineer cannot fulfill his role of trusteeship in modern industrial society.

Professional life is one of the few areas of experience where there is a whole which is more than the sum of the individual parts. Each has his daily work to do, but there is a total job for engineers to do collectively beyond the total to which the daily tasks add up. The parts have flourished magnificently, but the whole is yet to be created. No one possesses a blueprint of it. When it comes it will be a product of evolution rather than design. Search for it must engage our best minds and be a goal for our strongest organizations. This is not a role for minor prophets. Before there can be national unity on the plane above specialization, there must be local unity. That is the way of democracy. The thing to be done is to plant the seeds of such unity, to cultivate and fertilize them, in order to encourage and speed the course of evolution and to guide it toward high and not petty ends. The Institute, as the largest of our national engineering bodies, and the only one with a solid trinational basis, has a special obligation to foster this effort, while assiduously cultivating its own distinctive field. This has been the goal to which your officers and directors have dedicated their unstinted effort during the past year.

Short Survey of Japanese Radar—I

ROGER I. WILKINSON
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The result of a study made immediately following the fall of Japan and recently made available for public information, this 2-part report is designed to present a quick over-all evaluation of Japanese radar, its history and development. As the Japanese army and navy developed their radar equipment independently of each other, Part I of this article concentrates on the army's contributions.

RADAR IN JAPAN dates back to 1936 when credit is given to Professor K. Okabe of the University of Osaka for devising an electronic method for detecting the presence of passing aircraft.* At this time Professor Okabe was working under the famous Doctor Yagi, dean of science at the university. In his method, a radio transmitting station sends a continuous radio frequency signal, with superposed audiomodulation in as narrow a beam as convenient, to a distant receiving station. If an object such as an airplane enters the transmission path, the normal uniform signal or tone heard at the receiving station is disturbed and, instead of being steady, comes in with a strong beat note. This is an application of the well-known optical Doppler effect.

The Japanese classify their radar sets under two generic headings:

Type *A*—Continuous wave or Doppler systems.
Type *B*—Impulse systems.

According to Professor Yagi, the idea for type-*A* radar equipment arose following a trip he made to Germany before the first World War during which he became greatly interested in supersonic signaling. Upon his return he performed a number of experiments in this science which led him and Professor Okabe to study the effects of the presence of foreign objects in radio fields. It was not until the middle 1930's, however, that Japanese military people became much interested in such detection problems. They then encouraged Professor Yagi and his associates to apply their knowledge to the advancement of war techniques. Professor Okabe was a leader in the electrical engineering school at Osaka and was given the assignment. He proceeded forthwith to run many laboratory and field experiments on Doppler detection for the army and navy. The method had the great advantage of requiring only very small amounts of power. It had the decided drawback, however, of not giving the definite location of the target along the line between the sending and the receiving stations. Professor Okabe and his assistants tried long and hard to solve this problem, but unsuccessfully. In 1938 a large power output set was required to be used; in 1939 a much smaller set was adequate (three watts) and was used experimentally and practically at Hankow. In 1940 various sets with powers from 3 to 400 watts were built. The first Doppler system for aircraft warning was set up in 1941.

It is claimed vehemently by the Japanese that their studies of Doppler detection were conceived quite independently of the suggestions made by Doctor C. W. Rice, of the General Electric Company, whose papers on the subject appeared in American journals in 1936. Be that as it may, all Japanese radar research and development engineers are familiar with Doctor Rice's writings.

It was not until 1940 that the idea of type-*B*, or pulsed, radar equipment arose strongly enough for researches on this technique to be initiated. Its advantages were manifested so quickly that the chief effort thereafter was devoted to developing this method.

Unlike American practice, both systems were installed side by side in the army early-warning nets surrounding Japan, and facilities were provided at the information centers for simultaneously displaying the information from both. The Japanese navy also developed a type-*A* system but never put it into actual operation.

Type-*A* radar equipments (or detectors, as all early-warning devices are called in Japan) operating in the 40–80-megacycle band were found to give indications of the passage of aircraft across a fixed line in mountainous places where pulsed types were unsuccessful. They were operable also over much greater distances. The longest type-*A* line of detection used was from Formosa to Shanghai, a distance of more than 400 miles.

In 1937 the navy research laboratory was experiment-

* The term "radar" first appeared in Japanese papers near the end of 1944. The Japanese were under the impression that it was used in the United States only to describe the plan position indicator (PPI) search type of set found in B-29's. Instead of radar, the Japanese call early-warning sets detectors; searchlight and anti-aircraft fire control sets are known as locators.

Based upon an official report, "A Short Survey of Japanese Radar," prepared by the Second and Third Operations Analysis Sections for Headquarters, United States Army Air Forces, from studies made by the Analysis Sections and the Air Technical Intelligence Group, Far East Air Forces, United States Army.

Roger I. Wilkinson was operations analyst for the 13th and Far East Air Forces from October 1943 to December 1945. His assignment after the fall of Japan was to study all phases of Japanese electronics and radar from research to operations. He now is back with Bell Telephone Laboratories, New York, N. Y.

Acknowledgment is made of the services of Robert P. Featherstone, formerly captain, Army of the United States, who assisted in the collection of information contained in this survey.

Figure 1. Interior view of transmitter and power units of Tachi-6 which corresponds somewhat to the American SCR-270

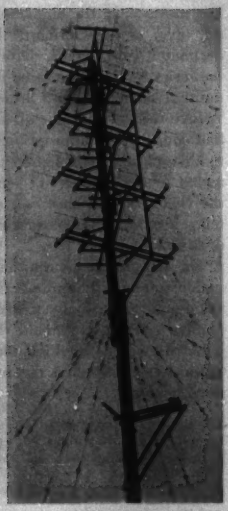

Figure 2. Tachi-6 transmitting antenna

ing with frequency-modulated continuous-wave radar, utilizing the same principle used in the present American and Japanese low altitude altimeters. In that year a large fleet parade was held in Tokyo Bay, and ranges were obtained up to five kilometers. This was considered unsatisfactory and the experiments were abandoned.

RADAR NOMENCLATURE

Before continuing with a discussion of later developments which will revolve about particular sets, it will be well to describe briefly the systems of radar nomenclature used by the Japanese army and navy. Japanese radar designations are about as confusing and difficult for the layman to remember as those used in the United States. Over a period of years, Allied radar intelligence people laboriously built up a background in Japanese navy sets, which, in general, were differentiated by four items:

1. Mark (Go).
2. Model (Kei or Gata).
3. Modification (Kai).
4. Type (Shiki).

Apparently this was too much for even the Japanese to keep straight, inasmuch as officers and men in their service usually referred to their equipment either by shortened numbers or by nicknames. For instance, the navy's 10-centimeter surface search sets mark 2 model 2 modifications 1 to 4 all were called simply number 22, while the night fighter's prototype 19 air mark 2 model 11 generally was called Gyoku-3.

The official designation system used by the Japanese Navy Technical Department was based on employing the following as the tens digit in the number assigned to any equipment:

1. Land-based search.
2. Ship-borne search.
3. Ship-borne fire control.
4. Antiaircraft fire control.
5. Panoramic indication.
6. Guiding type (ground controlled interception).

The second digit was supposed to be selected according to:

1. Fixed—for instance, number 61 was a fixed-type for guiding or ground controlled interception.
2. Mobile—for instance, number 12 was a land-based search set on a trailer.
3. Portable—for instance, number 13 was a lightweight land-based search set.

In the case of the 2-ship-borne series, however, the second digit refers to a wave length code and not to the degree of mobility. Japanese navy people readily admitted that this system of numbering was far from perfect.

Unofficially, the Japanese navy research laboratory gave each set a name or number as met their whim.

For instance, in the air-borne set FD-1, the "F" stands for "fly," or the German "flutzeig," and the "D" for decimeter wave length. Number 1 was the first one of the series built on the same fundamental designs. The unusual name Gyoku-3 arose from the Japanese word "gyoku-sai," meaning "all-suicide," which may have had considerable appropriateness, inasmuch as this was to have been a night fighter radar set. The letter "K" added to the numbers of certain sets does not refer to the year 1943, as once was suggested in American intelligence, but stands for "kantau" which means simple or simplified.

The Japanese army also had a fairly logical set designation system. The numbers were assigned during development and usually stayed with the set. The type number of each equipment was preceded by one of the following words, in which the prefix "Ta" comes from "Tama Institute" and the suffix from a characteristic word, giving:

Tachi, meaning land-based ("chi" from tsuchi meaning earth).
Tase, meaning ship-borne ("se" from misui meaning water).
Taki, meaning air-borne ("ki" from kuki meaning air).

ELECTRONICS RESEARCH

Electronics research was handled entirely separately by the Japanese army and navy. Much of the navy work was done by research laboratories directly under the navy ministries. The army, however, assigned more of its pure research to various universities and technical institutes. At the same time several of the larger radio and radar manufacturers were engaged actively in vacuum tube and materials researches, some by direction of the military people, and the rest through their own inspiration. Besides this, of course, the manufacturers were engaged with the problems, many of which bordered on pure research, of trying to meet the specifications for sets ordered by the two services. Incredible as it sounds, engineers and research men in electronics at the large manufacturing companies seldom were told how their equipment worked in the field; they were not allowed to go on shipboard to inspect an installation to say nothing of watching a radar set in operation. Likewise they were not permitted to visit ground radar installations in the field. Consequently, the men doing much of the designing of the equipment had very little means for observing and correcting their mistakes, an almost insurmountable obstacle in the road of rapid development.

Professor Yagi, well known for his antenna designs, was nominal head of civilian fundamental research. He was outspoken in his criticism of the manner in which the high commands had neglected electronics research on a broad front. In the early days of the war both army and navy officials could not be convinced of the tremendous value that radar might be to them in the defense of their islands. They thought in terms of being always on the offensive, while radar was considered primarily a defensive weapon. Thus they backed only a comparatively leisurely program of radar development. When the top Japanese militarists found they had guessed wrong it was too late to try to catch up with Allied developments.

There was a small number of very able and well trained scientists in Japan, principally in industry and in academic circles. It is of interest to note, however, that in no cases were projects of any great importance turned over to the universities to direct and carry through as they thought best. Usually, small studies, carefully circumscribed by military directives, were parceled out to an individual professor to work on. Often he had no idea of its ultimate use in the radar field. As a result, the utilization of civilian scientific talent, as contrasted with a nearly 100 per-cent mobilization in the United States and Great Britain, was very small and in this way the severe scarcity of first-rate electronics men in Japan was aggravated further by the military's unintelligent direction of their abilities. The meagerness of the program of fundamental electronics research is indicated by the fact that at the close of the war the army had only 39 projects assigned to 13 outside agencies other than the manufacturers.

Figure 3. Tachi-2 with transmitting and receiving antennas mounted together on the same mobile trailer mount

DEVELOPMENT OF ARMY RADAR SETS

In 1940 a Japanese technical commission spent several months in Germany and returned with reports of pulsed radar equipment being built in England. This gave new impetus to farseeing officers in the Japanese

army and navy to make further studies of its possibilities. Accordingly, the first researches in the army's search radar sets were initiated in 1941.

To co-ordinate the various projects which were beginning to spring up in the army's radar investigations, a research group, called the Tama Research Institute, was formed in 1943 under the leadership of Lieutenant General Suda. This institute was charged with responsibility for all radar research for the army. It also provided a consulting service for the army forces operating the equipment. For example, it assisted in selecting sites in difficult cases. When continuing trouble arose in certain sets, Tama attempted to find the answers.

The institute's laboratories, which were located in the western outskirts of Tokyo, were bombed heavily on April 3, 1945, and about 50 per cent destroyed. Various sections of the research work then were dispersed to other parts of Japan.

The staff of the institute comprised 88 officers and 96 trained assistants. There were an additional 600 persons on the payroll, of whom about half had some technical knowledge. The rest were stenographers, guards, and similar help.

The institute's appropriations for the past three years were:*

1943—12,000,000 yen

1944—16,000,000 yen

1945—16,000,000 yen (of which only about 7,500,000 yen were spent)

These figures included certain costs for models constructed, and of the remainder, 80 per cent was spent for experimental work and 20 per cent for fundamental research.

A summary of Japanese army radar equipment which had been developed or was under study at the end of the war is given in Table I. The information for this table, furnished by Tama Institute, omitted one notable equipment series known as Taki-24 and 34, microwave airborne extensions of Taki-14, with many features paralleling modern American search equipment. The development of this series was discovered only after considerable tracking down of rumors of its existence.

ARMY SEARCH RADAR SETS

As a general rule, Japanese search radar sets were designed for simplicity of operation and presentation. A single *A*-oscilloscope showing range was the usual case. Bearing was obtainable only roughly through guessing at what point the maximum signal was received. The height-finding radar sets, Tachi-20 and Tachi-35, had more elaborate displays. Resort to pip matching on an azimuth and elevation oscilloscope was the procedure in these cases.

The first army set to be built was the rough prototype of what is now known as Tachi-6. This is the large fixed installation used for primary early warning and corresponds somewhat to the American SCR-270. Frequencies assigned varied from 68 to 80 megacycles. It made use of one transmitter looking either in all directions or over a rather wide fixed arc, with a series of receivers, each looking over a much narrower but movable angle. The first Tachi-6's were produced in 1942 with powers ranging from a 10-kw to 50-kw peak. Figure 1 shows the transmitter and power unit of Tachi-6 while Figure 2 shows the antenna installation at Shimoda, one of the main warning locations, 150 kilometers southwest of Tokyo.

Portable sets were needed to supplement the ponderous Tachi-6 equipment, which was ill adapted for use outside of the home or mandated islands. Accordingly, the mobile Tachi-7, weighing 18 tons including vehicles and operating at 100 megacycles, was developed in the same year. It was ready for service in 1943, and most of the 60 sets manufactured were sent overseas, where mobility and ease of handling were of great importance.

A still lighter set was needed for portable service. For this, work on Tachi-18 was begun early in 1943, and a 100-megacycle set weighing only four tons was completed at the end of the year. These latter sets were retained mainly in Japan, where they provided a standby for Tachi-6 or assisted in reading through Allied jamming signals.

Tachi-6, like the American SCR-270, gave only the barest information on airplane heights. Tachi-20, with lobe switching in both azimuth and elevation, was installed at Choshi in March 1945, and Tachi-35, with goniometer pick-ups from pairs of azimuth and elevation antennas, was installed at Matsuda in May. These sets, working in the 80-megacycle range, were the army's attempt to answer the height problem. They were only partly successful.

In late 1942 the army began studies on a radar set to be installed on transports and other large ships for protection against Allied submarines. This led to the building of the 15.7-centimeter Tase-2 set by the Nihon Musen Company. In February 1943, installations were made on two ships, but the set did not have sufficient power to give satisfactory range, so it was earmarked for use on land. A second marine set, Tase-10, operating at 150 megacycles, was produced in December 1944. This set was designed expressly for use on transport submarines. However, upon its completion, Japan had left only one submarine of size suitable for its installation, and this installation proved abortive when the submarine's power supply was found to be inadequate.

The first army air-borne set, Taki-1, was built by the Nihon Musen Company in 1943, with only six months

* The current military rate of 15 yen to one dollar is likely to be rather misleading as to the magnitude of the budgetary figures. The average factory worker in Japan is paid from seven to ten yen for a 10-hour day, or, say, one yen per hour. For equivalent work, factory employees in the United States would be paid perhaps one dollar an hour. For a rough estimate of the equivalent American purchasing power allotment for these activities, the figures given might be considered dollars.

elapsing between drawing board and installation. Taki-1 operated at 200 megacycles with a 10-kw peak output, weighed 150 kilograms, and was for use on heavy bombers. Presentation was on a simple *A*-oscilloscope with a scale laid off by range marker pips. A certain amount of directional searching was obtainable by switching transmitter and receiver to any one of three antennas, a nose Yagi antenna, and a doublet on either side of the fuselage. This set was considered very satisfactory for sea search, giving ranges of 50 kilometers or more on large ships, and more than 1,000 sets were built. Smaller and lighter editions came out from time to time.

It was appreciated that greater definition in the oscilloscope presentation than that given by Taki-1 was desirable. Accordingly, in August 1943, research was started on a centimeter wave length air-borne radar called Taki-14. The first set, operating at 27 centimeters with a triode transmitting tube, was completed in August 1944 under the direction of Major Uozumi of Tama Research Institute. The antenna was a Yagi array with a paraboloid reflector. The set, when installed on a heavy bomber, gave maximum ranges of only 25–30 kilometers, which was thought not nearly good enough. By a series of experiments on the transmission lines and the antenna, the ranges were stepped up to 40–50 kilometers by February 1945. Production was made very difficult by the B-29 bombings of the plant doing the manufacturing, so that no sets actually were installed and in use by the end of the war in August. Continued experiments during this period involving the use of cavity tuning had brought the range up to 70–80 kilometers. The disposition of this latest experimental air-borne equipment is described poignantly by Major Uozumi, project engineer on Taki-14.

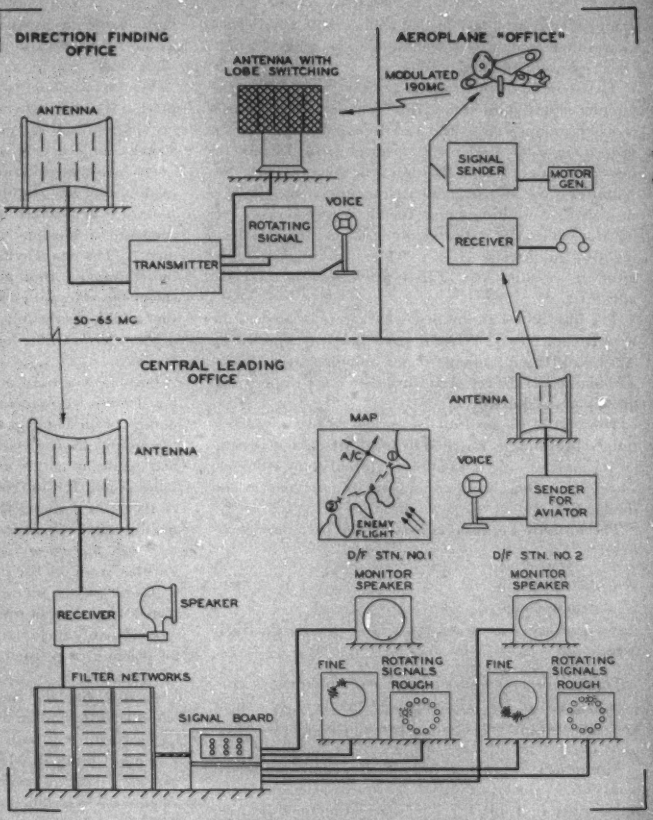

Figure 4. Taehi-28 multiple fighter control system

"On August 14th in this year, the war situation became too imminent to continue the research in laboratory even for our technical officers. We were obliged to prepare as we were able to go to the front to die—I dare say 'to die.' Thus at last we partialized and burnt down all our lovely sets (please pardon me to say 'lovely') with all important documents of investigations or experiments, and then we suddenly met the end of war before we went to the front as you know. I'm very sorry as one engineer that we partialized and burnt down to ashes all the sets and technical documents. I can say with my responsibility that we would have never burnt our lovely sets if we knew the war would end on August 15 at once, and you American Army or Air Forces would land such peacefully as we saw actually."

Paralleling the development of Taki-14 at 27 centimeters were studies at Tama Institute using the identical equipment with the radio frequency circuits altered to accommodate 10-centimeter transmitting tubes, thus producing Taki-24. At the same time, a 5-centimeter

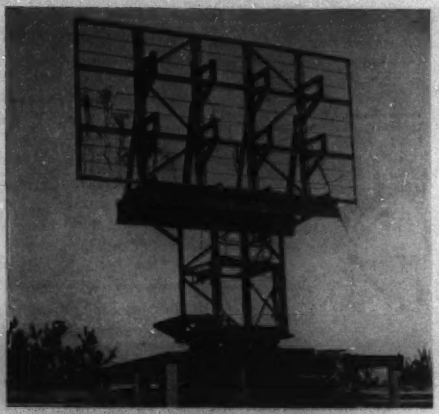

Figure 5. Direction finding antennas

set called Taki-34 was under development which used a magnetron for transmitting and a velocity-modulated tube for the local oscillator. A plan position indicator (PPI) presentation with sweep corresponding to the position of the paraboloid antenna was employed with magnetic deflection coils on the oscilloscope. It was developed after seeing the construction used on B-29's which had crashed over Japan. This set was turned over to Tama engineers in July 1945. It never was test flown, but experiments from a high point of land at Ajiro on the peninsula south of Tokyo showed the disappointing ranges of only 12–15 kilometers on nearby mountains.

LOCATOR-TYPE RADAR SETS

In 1942 one Japanese officer and two civilian engineers went to Singapore and Corregidor to inspect captured English and American radars. At Singapore they found the equipment almost entirely demolished. However, according to Japanese accounts, they discovered one complete set of drawings and specifications for a searchlight or fire control radar. At Corregidor several SCR-268's were captured, one of which was in complete operating order.

Tachi-1 and Tachi-2, the first two locators designed by the army, show strong indications of British searchlight control influence. Both are 200-megacycle sets, Tachi-1 having separately mounted transmitting and receiving antennas, while Tachi-2, as shown in Figure 3, has them together on the same mobile trailer mount. A phasing ring is used in both cases to give the receiver lobe generated by the four Yagi antennas a rotary movement. A mechanical distributor is used to switch the received signal at appropriate moments to the azimuth and elevation oscilloscopes. Tachi-3, which became the army's chief fixed position fire control reliance (150 were produced), was patterned after the British gun laying mark II equipment. It was rated at 50 kw at 78 megacycles and had a claimed range of 40 kilometers. Color disks were used for pip matching in both azimuth and elevation.

At a typical army antiaircraft defense layout, such as at Kawasaki, ten miles below Tokyo guarding the southern approaches to the capital, both Tachi-2 and Tachi-3 would be installed to control six 120-millimeter guns arranged in characteristic circular positions, and six 88-millimeter guns in a semicircular design. Tachi-2 often was camouflaged by a barn which rolled back on railroad tracks when the set was to be used. It is perhaps of interest to note that the Japanese navy acquired a Tachi-3 for experiment and comparison with navy fire control sets at their Chigasaki field laboratory. They found that it had greater range than their own S-3 and S-24 equipments, but that its bearing and elevation accuracies were not as good. Consequently, they considered their navy sets superior for searchlight and fire control purposes.

Tachi-4 was a mobile locator built to replace Tachi-2, but it proved unsatisfactory in operation. In this set the transmitter and receiver were combined to simplify the assembly. Finally Tachi-31 was built from modifications of Tachi-4 and became the standard 200-megacycle radio locator for the army. This 10-kw set used all four Yagi antennas for transmitting and receiving, thereby giving greater range and directional definition (range, 40 kilometers, azimuth and elevation accuracy plus or minus one degree).

At the same time that the 200-megacycle development was going on, slow progress was being made in building an exact copy of the German Small Wurzburg (Tachi-24), which would operate at a 50-centimeter wave length and give a much improved azimuth and elevation accuracy (in the order of one-eighth degree). Plans for this set and the major components had been brought from Germany by submarine in January 1944. Reengineering to Japanese specifications and parts required several months, and the first of three sets to be made by Nihon Musen as models for the Sumitomo and Tokyo Shibaura companies to copy was nearing completion in August 1945.

In all of the foregoing fire control sets, the data are sent to mechanical gun directors by means of a Selsyn-type system.

The army just was beginning to produce a locator for use on aircraft as the war ended. This was Taki-2, an 80-centimeter set with a single Yagi transmitting antenna and four similar receiving antennas switched in rotation for azimuth and elevation estimating. It does not seeml ikely that this set would have given sufficient directional accuracy for much success as a night fighter.

Table I. Summary of Radar Equipment Developed by the Japanese Army

Figures Given Indicate Maximum and Minimum for Each Classification

Classification	Number of Types Designed	Objective	Frequency (Megacycles) or Wave Length (Centimeters)	Power Output	Range	Weight	Total Number Produced
Warning Radar							
Ground	9	Fixed and mobile aircraftwarning systems	68–106 megacycles	to 50 kw	to 300 kilometers	100 kilograms–18 tons (including vehicles)	825
Ship-borne	3	Detection of ships, aircraft, submarines	15.7 centimeters; 150 megacycles	to 50 kw	to 300 kilometers	100 kilograms–4 tons	111
Air-borne	2	Detection of ships and submarines	150 megacycles	10 kw	to 100 kilometers	80–150 kilograms	1,000
Locating Radar							
Ground	6	Fires firing data for antiaircraft guns	78–200 megacycles; 50 centimeters	to 50 kw	to 40 kilometers	1.5–4 tons	341
Air-borne	2	Night interception	80 centimeters	2 kw	to 8 kilometers	120 kilograms	in production
Leading Radar (Offensive fighter aircraft directing)							
For single aircraft	2	Indicates position of friendly aircraft	175–184 megacycles	to 10 kw	150 kilometers	25 kilograms–1.5 tons	70
For several aircraft	2	Same	190 megacycles		300 kilometers	25 kilograms–500 tons	51
Directing equipment	3	Computes interception course and transmits it to airplane				20–500 kilograms	models completed
Identification—friend or foe	4	Identification of aircraft	175–184 megacycles	100 watts (airborne); 10 kw (ground)	250 kilometers	25 kilograms (airborne) 1.6 tons (ground)	120; 50
Navigation Radar							
Hyperbolic curve navigation equipment	2	Computation of two curved lines for navigational purposes	1.5 megacycles	150 kw	to 3,000 kilometers	50 kilograms (airborne) 600 tons (ground)	model completed
Night Radar	4	Identification of condition of terrain for bombing and navigation purposes	5–27 centimeters	2 kw	radius 20 kilometers at 5,000 meters altitude	120 kilograms	models completed
Radar altimeter	3	Computation of distance from aircraft to ground	375 megacycles Fm and pulsed	to 200 watts	to 50 meters and 12,000 meters	25 kilograms	in use
Search Receivers	4	Detection of enemy radar	3 centimeters–15 meters		to 300 kilometers	32–250 kilograms	50 sets in field
Radar jamming	2	Jamming of enemy radar	0.8-7 meters	continuous to 70 watts; impulse to 1 kw		200 kilograms	10
Special equipment							
Special aircraft control	2	Guiding of gliders	200 megacycles			50 kilograms–2.5 tons	Under research
Homing equipment	2	Detection of, and adhering to, electric waves reflected or sent from ships	300 megacycles to 7.5 meters	70 watts	to 5 kilometers (expected)		Under research

ARMY LEADING RADAR FOR GROUND CONTROLLED INTERCEPTION

The Japanese were trying hard to solve the problem of ground controlled interception as the war ended. For this they had built a ground interrogator, Tachi-13, transmitting at 184 megacycles per second and receiving at 175 megacycles per second. This was to work with the transpondor Taki-15 installed in the airplane both to identify and fix the position of the night fighter. Display was on two *A*-oscilloscopes, one giving range, and the other giving bearing by means of pip matching. This would have been quite similar to using the American RC-184 for guiding an interceptor, something which could be done only with exceedingly skilled plotters and controllers. Presumably the 200-megacycle Tachi-31 or the Wurzburg (Tachi-24) would have been used for fixing the position of the enemy airplane at any moment.

In order to handle more than one air interception at one time, a combination of equipments called Tachi-28 was in the process of being built, by means of which as many as 30 friendly airplanes could be guided simultaneously (see Figure 4). Each airplane to be controlled carries a transmitter (Taki-30) radiating a continuous signal at 190 megacycles and modulated at some assigned frequency between 30 and 60 kc. Two or more direction finder (DF) stations located at intervals of about 50 miles pick up the signals. Their antennas (see Figure 5) rotate steadily at two revolutions per minute, and each is arranged by 50-cycle lobe switching to have a horizontal pattern with two maxima and a sharp minimum between them.

The composite signal picked up by each direction finder station—a mixture of tones from 30 to 60 kc—is radioed to a control station on a special 5-meter link. (Some of the central station equipment is seen in Figure 6.) In the region below the lowest aircraft signal frequency (from zero to 30 kc) a voice channel and an azimuth signal are transmitted. The latter indicates the position of the direction finder antenna and is in two parts: one, for fine data, is continuously variable and repeats itself every 30 degrees; the other, for coarse data, varies in 12 steps. At the central station the coarse azimuth signal lights one of 12 neon lamps, while the fine azimuth signal positions the spot of a cathode ray tube causing it to go through a circle for each 30 degrees of the direction finder antenna's travel. The signal of the particular airplane being observed is selected by a filter and displayed radially on the cathode-ray tube. The minimum in the center of the observed figure which appears on the oscilloscope is at the azimuth of the airplane. The operator locating an airplane has two oscilloscopes before him, one for each of the two outlying direction finder stations. From the data of both stations he can locate the airplane quite accurately. Other operators use the same azimuth signals but select different aircraft signals.

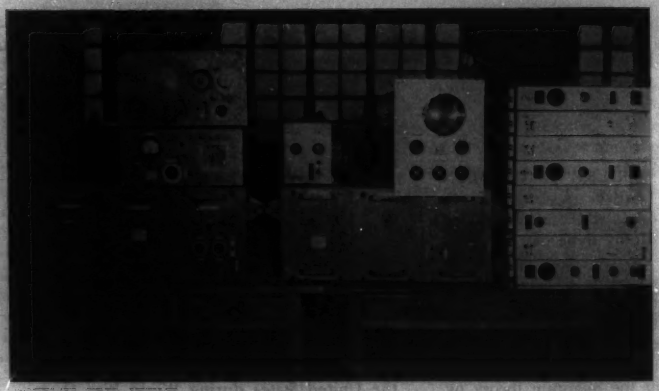

Figure 6. Tachi-28 central station equipment

Left—Fine indicator, coarse indicator, auxiliary equipment
Center—Monitor oscilloscope, equipment to develop circular sweep
Right—Filters for airplane signals

This system was intended for ground controlled interception use and the first units were being installed in the Tokyo area as the war ended. The central station was located at Matsudo; initial direction finding stations were at Choshi and Shirahama, 50 miles east and south, respectively, of Tokyo. In some cases relay stations were to be used in the 5-meter radio link. This system is of possible interest to American engineers studying airport and airway traffic control as it provides instantaneous remote indications of a large amount of data: two direction finder cuts a minute on each of 30 airplanes.

The transpondor used with the Tachi-13 previously mentioned is really an identification-friend-or-foe set and ordinarily would be used with the Tachi-13 or Tachi-17 on the ground as the interrogator–receiver in the projected identification-friend-or-foe system. Tachi-17 is a simplified Tachi-13 giving considerably less directional accuracy.

There is considerable doubt that the foregoing measures would have gone very far toward solving one of Japan's most urgent problems: how to knock the B-29's out of the sky in such numbers as to interfere seriously with their bombing operations. Even the United States forces, with their much superior plan position indicator oscilloscopes for ground controlled interception, and their 10-centimeter airborne radar interception, would have had great difficulty in slowing down such an attack.

50 Years of Physics

GORDON F. HULL

In the years prior to the 20th century the names of American physicists, with two or three notable exceptions, were conspicuous by their absence from any roster of world-acclaimed scientists. The discovery of the X ray in 1895, however, marked the beginning of a new epoch in physics and during the succeeding 50 years Americans gradually attained eminence in this field. Today, as a result of the developments coming out of the United States during World War II, as well as the war's disastrous effect on scientific progress in other countries, at least three-fifths of all the physics activity in the world is centered in the United States.

THERE HAVE BEEN two transcendent periods in the domain of physics during these past 50 years. The first began with the discovery in 1895–96 of X rays, followed by the discovery of the Becquerel rays in 1896, the electron in 1897, radium in 1898, and the statement of the quantum theory by Planck in 1900. The second period also began in 1896 but, slowly growing, culminated in 1939. Vast vistas suddenly were opened in 1896. There had been no theory or experiment which had foretold the discovery of X rays. A similar statement may be made concerning radioactivity and the quantum idea. The timeliness of the discovery of X rays and the electron is shown by the fact that two of the three kinds of rays which came from a complex radioactive source could be explained at once. The nature of the third ray, though quickly postulated by Rutherford, was not established convincingly until the Rutherford and Royds experiment in 1908. Then the process of transmutation of the elements as it occurs in nature was made plain. The way was open for all the vast results which have followed.

AMERICA'S CONTRIBUTIONS

It is not the purpose of this article to attempt to record the progress of physics in all its great domains during these years but only to present a few contrasts.

It has been noted that no American physicist participated in any of the great discoveries which have been mentioned.[1] Perhaps that statement should be modified as will be indicated later.

In 1899 Arthur Gordon Webster, a distinguished Harvard graduate and one of the most prominent American physicists, called together the leading physicists, chiefly of the east, for the purpose of organizing the American Physical Society. Appropriately, Henry Rowland was elected president and A. A. Michelson, vice-president. When Rowland was retiring, he named, in his address, the only four American physicists who, in all the previous history of America, had won world-wide fame for their contribution to physics—Franklin, Rumford, Henry, and Mayer. The many-sided Franklin, a legendary figure, had won fame along various lines. Had he not been famous as a publisher and a statesman (at 80 years of age he was still the United States' chief maker of treaties) he might never have been heard of as a scientist. Balzac described him as "the inventer of the lightning rod, the hoax, and the republic." It has been maintained that there is no clear evidence that he ever performed the kite experiment and it is certain that the experiment was performed elsewhere before Franklin wrote of it as a possibility. In any event, Franklin's work in science did not lack for publicity.

Rumford left America as a very young man. He was always a British subject and did all his scientific work in Europe. He hardly could be called an American scientist. However, he was interested in the development of science in America as is evidenced by the Rumford Medal of the American Academy of Arts and Sciences, the Rumford Fund of that academy, and the Rumford Professorship in Harvard University.

Joseph Henry's work in electromagnetic induction was substantial, but was overshadowed by the work of Faraday.

Who was Mayer? Many physicists do not know, but A. M. Mayer (1836–1897) was professor of physics at Stevens Institute and was the coauthor of a very modest text (112 pages) on light. His contribution to physics does not seem to have been recorded in any history of physics. The fame of a teacher is likely to be transient.

Rowland's list then of American physicists who, before his time, had made substantial contributions, boils down to two names—Benjamin Franklin and Joseph Henry. Had he included living Americans he would have added two more, himself and A. A. Michelson. The contributions of these two men have been acclaimed by the entire world. Rowland's experiment on the magnetic effect of convection currents, begun in

Essential substance of an address before a meeting of the American Physical Society, Cambridge, Mass., April 25–27, 1946.

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Helmholtz' Laboratory, made clear to J. J. Thomson the nature of the electron. To that extent an American physicist participated in the discovery of that particle. Rowland's exhaustive experiment on the mechanical equivalent of heat was financed by the Rumford Fund of the American Academy of Arts and Sciences and his extensive paper was published in the proceedings of that academy. He had had difficulty in finding an American publisher for some of his earlier papers but Clerk Maxwell came to his rescue and had them published in the *Philosophical Magazine*.

In addition to these discoveries, by 1900 American physicists had contributed the design of the concave grating; the building of an excellent machine for ruling gratings (the machine which still is ruling gratings for the world); the Michelson-Morley experiment (perhaps the most important experiment ever to be performed in America); and the measurement by Michelson of the French meter in wave lengths of cadmium light, an experiment carried to a precision which never has been exceeded,* a precision of one part in 20 millions.

EUROPE AS MENTOR

Fifty years ago graduate training in physics was looking up in America but it still was true that every young physicist believed it necessary to spend at least a year in Germany or in the Cavendish Laboratory in Cambridge. Europe was the source of inspiration. Ideas came from Europe as well as 90 per cent of all apparatus in American physical laboratories.

However, not only were the leading laboratories in the United States rapidly expanding, but two in Canada, Toronto and McGill, were being heard from. In 1898 the 27-year-old New Zealander, Rutherford, came from Cambridge to McGill University as research professor in physics. Soddy came from Oxford to join him in 1900. Together, in 1902, they put forth the startling theory that radioactivity was a spontaneous natural process of transmutation of certain elements. This idea seemed so preposterous that the authorities of McGill University were afraid that the university would be held up to ridicule. But the physicists of the world presently were convinced that the theory was right and McGill University became a mecca for workers in radioactivity. Among those who came was Doctor Otto Hahn, in 1905, who, with Strassmann in January 1939, made the announcement which was to have such world-shaking effects—that uranium atoms bombarded by slow neutrons break up so that barium is produced. The explosion of the atomic bomb was an eruption which, in physics, had been gathering force for 40 years. The rest has been told in millions of words in the press and journals since August 6, 1945.

To show that no artificial dividing line separates the physicists of one nation from those of another, an amusing incident may be told which occurred during the year or so that Hahn was at McGill University. A photographer came to the laboratory to photograph Rutherford for *Nature*. Rutherford's shirt, however, had no cuffs to speak of and the photographer was shocked. Hahn had a pair of detachable cuffs. These were slipped under Rutherford's coat sleeves and the photographer's sense of dignity was satisfied. In the photograph the face is that of Rutherford but the white cuff so prominently displayed belonged to Hahn. Years later, recalling the inspiring period he had spent in association with Rutherford, Hahn writes of this incident as "one of the beautiful memories of my life."

Although the "genealogical tree" of the radioactive products of uranium had been set forth in 1902 on the basis that the alpha particle was a helium atom of charge two and mass four, there was still doubt about it when Rutherford left McGill University for Manchester in 1907. In a letter to Hahn in 1907 Rutherford writes that "it may yet turn out that the alpha particle is hydrogen and that helium comes from a rayless product." The author made this proposal in 1904 when Rutherford lectured at Dartmouth College and doubtless it has been made numerous other times but within a year after reaching Manchester, Rutherford and Royds proved the helium idea the right one. In this same 1907 letter to Hahn, Rutherford expressed pleasure at the prospect of getting back to England for, he wrote, "I shall be glad to be nearer the scientific center as I always feel that America as well as Canada is on the periphery of the circle." What would he say now with at least three-fifths of all the physics activity in the world centered in the United States!

To see what a long road it was from the discovery of radium in 1898 to that of the fission of uranium in 1939 one may follow Rutherford's career in Manchester and Cambridge. Hans Geiger had been an assistant of Professor Schuster in Manchester and was retained as Rutherford's assistant. As a result, in 1908, the Rutherford and Geiger device for counting alpha particles was evolved. Later, in Germany, Geiger improved upon this device and still later, 1928, the Geiger–Muller counter was brought out. This instrument enables the measurement of electric currents to the absolute limit of smallness. A person can be given food containing radioactive atoms and, at a later time, this counter can find the chief concentration of those atoms in the body.

Rutherford for some time had been wondering about the structure of the atom; whether it was like the "pumpkin" atom of J. J. Thomson, or whether it was a solar nucleus with electrons outside. Nagaoka had suggested a "saturnian" atom, a central massive portion with a ring of negative electrons. Rutherford worked out the theory of the scattering of alpha particles on the basis of the nuclear idea and Geiger, later Geiger and Marsden (1912), tested the theory by counting the number of alpha particles scattered at various angles.

* This precision may be surpassed in the future by using the green line of the new isotope of mercury.

Their results supported the nuclear idea. Niels Bohr spent some months in Manchester at this time and was quick to use the new picture of the atom in his famous theory of the spectra of hydrogen. Moseley, who was with Rutherford for three years, also confirmed the nuclear view and established, in 1913, the concept of the atomic number, the number which has been used ever since to identify chemical elements. Moseley, who accomplished more in his brief lifetime than most scientists who live three score years and ten, was killed at Gallipoli in August 1915 at the age of 27.

EFFECT OF WORLD WAR I

When World War I intervened to check ordinary scientific research, Rutherford, Hahn, and Geiger, who had gone back to Germany, corresponded during the war by roundabout methods, all letters showing continued respect and cordial good will. In contrast with this evidence of friendship, one does not hear of any friendly letters during World War II from a German scientist to a scientist outside Germany. The reason is not difficult to discover. The scientists left in Germany, for the most part, felt that they belonged to a superior race. Those who did not have that belief dared not write.

Chadwick carried on research with Geiger in Germany just before World War I then was interned during the four war years but was treated well. Geiger's letters to Rutherford always gave assurances to that effect.

In 1919 Rutherford discovered that a nitrogen atom bombarded by an energetic alpha from radium could be transmuted into a new oxygen atom and hydrogen. The laborious method of observing the scintillations of a fluorescent screen was used to detect this result. For the first time in man's history the atom of a *stable* chemical element—the imperishable element of the chemists—was transmuted into another. The projectile used in this experiment was man-directed, but not man-made. It was a projectile provided by nature, its initial energy could not be altered in any way by man. But if great and various energies could be given to various kinds of atoms what might happen? Cockroft and Walton (1932) in the Cavendish Laboratory were able to speed up hydrogen nuclei to an energy of only 150,000 volts and by directing these against lithium found that two helium atoms had been formed. Not only were new atoms formed, but apparently energy had been created, for the two helium nuclei together had an energy of 17,000,000 volts. What had happened was that the loss of mass resulting from the formation of the two new atoms had taken the form of energy—a concept which had been growing for some time. Einstein's historic equation, $E=mc^2$, had been verified.

THE AMERICAN PHYSICAL SOCIETY

To return to the paleozoic age of physics in America, the American Physical Society was formed with 37 members, some of whom were not physicists. There were to be four meetings a year, each meeting consisting of two sessions, one morning, one afternoon. In the first five meetings there was a total of 28 papers, three or four in the morning, three or four in the afternoon, and there was plenty of time for the papers and for discussion. At times R. W. Wood who had succeeded Rowland at Johns Hopkins University (1901) and who was known throughout the world as a brilliant experimenter gave some demonstrations of optical phenomena. Here a tribute should be paid to Wood for his many contributions to optics, for his outstanding text on physical optics, for his near discovery of the Raman effect, and for his exposure of Blondlot's claims regarding N rays.*

The proceedings and papers of the society were published in bulletins, four per volume. Volume one, covering the first two years, had a total of 80 pages. But at Cornell University E. L. Nichols and Ernest Merritt had started the *Physical Review* in 1894. This was taken over by the society in January 1903 and since then has been the chief official publication and a leading physics journal.

Just before Rutherford left Canada, O. W. Richardson came from Trinity College, Cambridge, to Princeton University from which the Comptons presently emerged. At the same time Pupin and others were building up Columbia University not only by their own work but by capturing prominent physicists for their department. They tried to get both J. J. Thomson and Rutherford there together in 1901 but neither would think of going to so isolated a place as the city of New York.

The sensational discoveries during the closing years of the 19th century energized the work in physics of all the great universities of America. Perhaps this was especially true of the University of Chicago where the name of Michelson and the energy and enthusiasm of Millikan attracted many graduate students. The measurement of the electron charge by the oil drop method and of Planck's constant by the photoelectric effect brought new precision at that time to those quantities. The graduates of the University of Chicago were destined to fill very responsible positions in the universities and in the great industrial laboratories.

Then Washington University stepped into the limelight. There A. H. Compton (1923) measuring the wave length of X rays scattered by matter found that the wave length was lengthened slightly and he gave an explanation of the effect based on Planck's quantum theory. Both his experimental results and theoretical reasoning were disputed by others but he conclusively proved his case.

The Compton effect made it clear that bullets of light, particles of radiant energy, photons, possessed momen-

* Blondlot of the University of Nancy in 1904 received a prize of 50,000 francs for the discovery of the N rays. Wood visited his laboratory, removed in the semi-darkened room some of the "essential" components of the apparatus. Blondlot still saw the screen light up.[3]

tum and energy, that waves of light have the properties of particles. At once, by simple mechanics, the result could be derived that light would give momentum to atoms or would exert pressure on a surface on which it fell, a pressure equal to the energy density in front of the surface. This latter conclusion had been derived by Maxwell from his electromagnetic theory and had been discovered experimentally by Peter Lebedew in Moscow and with considerably greater precision by E. F. Nichols and G. F. Hull in the opening years of the century.

An industrial laboratory stepped into the picture when Davisson and Germer (1927) of the Bell Telephone Laboratories proved that an electron possesses wavelike characteristics. G. P. Thomson in Aberdeen arrived at the same result nearly simultaneously. These experiments supplemented Compton's work and proved that particles have the properties of waves. They confirmed the theoretical work of Louis de Broglie.

All eyes turned toward India when Raman (1928) showed that light scattered by matter might differ in wave length from that of the original beam by amounts which could be explained by the quantum theory but which were completely unintelligible on the basis of the wave theory. India, which had had no place in physics at the beginning of the century, now attained and has continued to hold an honored position.

PHYSICS WONDER YEAR

The year of 1932 was a wonder year in physics. Chadwick discovered the neutron; C. D. Anderson discovered the positron; Urey, Brickwedde, and Murphy discovered heavy water; Cockroft and Walton brought about the transmutation of lithium by firing hydrogen nuclei into it; the latitude effect in cosmic rays was discovered; Van de Graaff devised his generator for high voltages; and E. O. Lawrence, with the help of his associates, brought the cyclotron to practical performance. The cyclotron since has grown to such dimensions that it may require an entire building to house it and three or four teams of specially trained physicists to operate it by remote control day and night and may, with its housing, cost as much as $2,000,000. Compared with Cockroft and Walton's 150,000 volts, it may give atoms speeds of 60,000,000 volts.

Of the seven afore-mentioned discoveries, two were produced in England, five in the United States. True, the two English contributions were of very great importance. Neutrons are known to be an important part of nature. In number or mass they are the chief constituents of all atomic nuclei, they are extremely effective bullets in breaking up atoms, and they are the detonators in atomic bombs. But the cyclotron is also of importance. By its means every known element has been transmuted into another.

Other discoveries were that of artificial radioactivity by the Curie-Joliots in 1934 and of the mesotron in 1936 by Anderson and Neddemeyer of the California Institute of Technology and by Street and Stevenson of Harvard University.

In 1934 Fermi and his numerous associates in Rome believed that by bombarding uranium by slow neutrons they had produced element 93. But they did not prove their case; indeed, there was great doubt about it. Hahn, Meitner, and Strassmann took up the problem and came to various conclusions, among them that transuranic elements as far out as 97 had been produced. Irene Curie and Savitch in 1937 thought that they had found lanthanum in the material but concluded that it must be a new transuranic element, 93, which had properties similar to lanthanum. (This would be reasonable inasmuch as the atomic number of lanthanum is 57. 57+36=93.) Then in January 1939, Hahn and Strassmann announced that the analysis of the material obtained by bombardment showed that barium was present. It was not there before the bombardment. It was not a transuranic element; it was barium, and if barium was present, so probably was krypton. That announcement produced an enormous upheaval in the domain of physics for never before had a heavy atom been broken up into two atoms roughly equal in mass.

Aston in his pioneer work with the mass spectograph had measured the masses of many atoms and had drawn a curve called the packing fraction curve showing the masses of the atoms. This was extended by Dempster so that competent physicists knew the masses of uranium, barium, and krypton. They knew the excess mass of the large atom over the sum of the two smaller masses and by a simple mental operation they could compute the energy which would result. This computation was made almost immediately by Lise Meitner and Frisch. Early in 1940 A. O. Nier separated, by the mass spectrograph, U-234, U-235, and U-238. Dunning, Booth, and Grosse proved that it was U-235 that was broken up. Then the great reservoir of power of the physicists of America and England broke loose to bring about in five years a result—the production of the atomic bomb—which at first thought would require 100 million years for its completion. For part of this story, a story with no counterpart in the history of man, the reader is referred to the Smyth report.

PHYSICS DURING WORLD WAR II

Some discoveries were made during World War II which should be included. In 1939, in the Berkeley laboratory, Edwin McMillan tentatively identified elements 93 and 94 (of mass 239) in uranium bombarded by slow neutrons. In 1940 he and Abelson made the matter certain. The names proposed by McMillan were neptunium (Np) and plutonium (Pu). Later in that year uranium was bombarded by 30-million-volt deuterons from the cyclotron and the 238 isotopes of these elements were obtained including enough of plutonium (0.5 milligram, one millionth of a pound)

to enable Seaborg, Kennedy, and Wahl to make a study of its chemical properties. Had plutonium not been discovered there still would have been no atomic bomb.

Another discovery was that by Seaborg of elements 95 and 96, for which he proposed the names americum and curium. These elements complete a list of eight chemical elements which were discovered, during the war, by physical means: elements 43, 61, 85, 87, 93, 94, 95, and 96. Incidentally, handbooks of physics and chemistry and charts of chemical elements list elements 85 and 87 as alabamine and virginium. These names must be striken out inasmuch as the magneto-optical method of identifying chemical elements, like the N rays, is an exploded fallacy.

A cyclotron may produce more radioactive atoms and bring about more transmutations than would be produced by all the radium in the laboratories of the world, and, in the very near future, uranium-plutonium piles or nuclear reactors may be available which may provide neutrons and gamma rays of great intrinsic energy and of unparalleled intensity.

However a new device, the betatron, for producing high energy particles, in this case electrons, has been developed by Kerst. One such instrument in the research laboratory of the General Electric Company gives to electrons an energy of 150,000,000 volts. The resulting X rays penetrate a foot of steel, produce transmutations, and generate mesotrons, thus providing man-made cosmic rays generated on the earth. However, both the cyclotron and betatron may be superseded by the synchrotron which promises to obtain energies of 300 million volts. This idea, proposed in 1945 by McMillan in Berkeley, seems to have been proposed previously by V. Veksler of Moscow in 1944 who is building a 30-million-volt instrument in that city.

STATE OF PHYSICS TODAY

What is the condition of physics today? In Germany, Japan, and parts of Russia science nearly has been destroyed. In France and England it has been curtailed greatly. In the United States, however, physics has reached a pinnacle never before attained. During the first 20 years of the Nobel prize awards only one American, A. A. Michelson, received the prize, and that was for work done 20 or more years earlier. Of those who received the awards in physics during the past 25 years, 12 are in America; and of the last nine medalists, eight are in America, four of whom are native-born. Half of America's Nobel prize winners in physics are recent arrivals from Europe, and there are other rather recent arrivals who are not inferior to some of the prizemen. All of these plus native American talent have given to research and teaching an unchallenged prestige. America's young men no longer feel that it is necessary to go abroad for thorough training or for opportunities for research. On the contrary, before the war there was an increasing number of applicants from abroad for admission to American graduate schools. In fact, so great has been the number of applications of students from abroad that some of the universities in America have had to impose a quota system so that native-born students would not be crowded out.

Of course membership in American physical societies has increased. Instead of the 30 or 40 members of the parent society in 1899 there are now 5,300 members in it and related societies (optical, acoustical, X rays, electron microscope, and physics teachers), a total of 10,000 or about 300 times the original membership. And instead of 20 or 30 papers a year there are now several thousand.

There has been a corresponding increase in research activities in universities and technical schools. It ought to be recorded that during these 50 years the number of students in American colleges and universities has increased by a factor of seven. For example, the Massachusetts Institute of Technology, originally purely an undergraduate technical institution, now is one of the foremost institutes of technology in the world. Originally research in pure science was out of bounds but gradually its field broadened. During the first 20 years of this century the institute awarded a total of four masters degrees and two doctors degrees in physics. Now it has 150 graduate students including those in three groups; the research laboratory in electronics, the laboratory of nuclear science, and the acoustics laboratory.

During the war the Massachusetts Institute of Technology cosponsored the Radiation Laboratory which, next to the Manhattan Project, was the greatest enterprise of the war with operating expenses of approximately $3,000,000 a month. In that laboratory numerous radar devices were designed and brought to perfection. The H2X air-borne set carried by heavy bombers so that targets could be found at night or through overcast, the Loran sets for long range navigation with which any vessel or airplane carrying a receiver could locate its position without chronometer or astronomical observation, the powerful MEW (microwave early warning) set which played so large a part in the invasion of Europe all came from the Radiation Laboratory. It should be noted here that the multicavity multiresonant magnetron essential in many radar devices is due to Oliphant of Birmingham, and the idea for the original magnetron to A. W. Hull of the General Electric Research Laboratory.

The University of California, on the Pacific coast, enrolls about 4,000 students in the undergraduate physics courses (3,000 different students), and at last report there were 120 graduate students and 100 clamoring for admission. These figures do not include the radiation laboratory of the monster cyclotrons. At present no information regarding that laboratory is available because it is under government control.

The California Institute of Technology has risen to

a leading place among the world's physics research laboratories with 300 undergraduates in physics and 80 graduates. Fifty years ago these figures were 12 and 0. On its physics faculty of 13 full professors there are two Nobel prize winners, one third of all the native-born American prize winners in physics. The California institute's great growth and prestige can be attributed to R. A. Millikan who has been its chief for 25 years.

In a brief survey only a few men can be named and so many may be offended. Among these may be mentioned the contributions of Theodore Lyman and Bridgman; Harrison and Slater; Aston, Dempster, and Bainbridge; Boltwood, Bumsted, and Swann; C. T. R. Wilson; Dirac; Schroedinger; Heisenberg and Bethe; J. A. Wheeler; and of many others.

THE FUTURE OF SCIENCE

The wonders of radar in all its forms, completely unknown 50 years ago, the discovery of the fission of uranium by Hahn and Strassmann, the production of the atomic bomb (about which this article says little in comparison with the millions of words that have been printed about it) by the combined scientific power of the United States and England, by the Canadian contribution of the essential materials, and by the vast industrial power of the United States, have given to American physicists a prestige never before enjoyed.

These scientists are not combative or competitive as are other social or economic groups and so should unite with the scientists of all other nations to outlaw war. No iron curtain should be allowed to enclose and segregate the scientists of any nation.

Science has attained a prominent place in the life of the nation but the methods of science have not changed greatly, although it is true that there is emphasis on teamwork in contrast to the efforts of an individual. Great laboratories supplied with very powerful and expensive apparatus can dwarf the work of ordinary college laboratories.

But what kind of people are you going to put into the large laboratories? What ideals are you going to place before them? Merely bringing a lot of men together in one building or center is not necessarily going to bring about progress in science. How did it happen that Chadwick discovered the neutron? He knew from Compton's work what a photon would do if it struck an atom. He knew from long established principles what an atom would do if it struck another atom. He could identify atoms by their ranges from the abundant data established by the labors of Rutherford, Blackett, and by himself. He possessed a great fund of knowledge. He possessed experimental skill and he was a tremendous worker. Would he have been helped or hindered by a lot of clock punchers? It is of vast importance that every teacher of physics in the colleges and universities be impressed with the view that progress in science depends on *his* knowledge of the domain in which he works, *his* scientific curiosity, *his* scientific imagination, *his* experimental skill and analytical ability, and that progress is likely to be accompanied by the scientific analogues of blood, sweat, and tears.

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New Process Polishes Silver Electrolytically

A process of polishing metals by electrolytic treatment now has been adapted for application to silver. In this method of "electroplating in reverse" a current opposite in direction to that employed for ordinary plating removes metal preferentially from the high spots to produce a mirror-smooth surface. It replaces manual and mechanical buffing.

Electropolishing in general is a relatively new finishing procedure which has developed during the last ten years. The most important application so far has been the polishing of stainless steel, and several large installations have been operating with strong acidic baths for a number of years. Aluminum, zinc, copper, brass, nickel, tin, cobalt, nickel-silver, and various iron alloys also can be polished in acid baths. However, these baths usually require a rather high current density which requires expensive equipment.

The new silver process differs from earlier methods for other metals in its simplicity and economy. Its alkaline cyanide bath is much the same as for silver plating and does not require heating. Current density also is in the low plating range, and plants thus may use their regular equipment. Inasmuch as electrical efficiencies are almost 100 per cent, power costs are very low, and silver continually is recovered from the bath, which thus has long life.

The process has been in use for polishing plated silverware at Oneida, Limited, for more than a year. The company also, as a result of research, has sponsored a project at Arthur D. Little, Inc., Cambridge, Mass.

The Automatic Sequence Controlled Calculator—I

HOWARD H. AIKEN GRACE M. HOPPER

With the increasing need for accurate computation occasioned by the use of numerical analysis in many scientific developments, as well as by the increased accuracy of physical measurement, more and more time and effort must be devoted to computational labor which is, moreover, always susceptible to human fallibility. As a step toward remedying the situation, the automatic sequence controlled calculator will carry out any selected sequence of the five fundamental operations of arithmetic (addition, subtraction, multiplication, division, and reference to tables of previously computed results) under completely automatic control. Part I of a 3-part article describes the mechanism and explains its function in addition and subtraction.

THE DESIRE TO economize time and mental effort in arithmetical computation, and to eliminate human liability to error, is probably as old as the science of arithmetic itself. This desire has led to the design and construction of a variety of aids to computation. After the invention of the abacus (about 3500 B.C.) 5,000 years elapsed before the next computing device was developed. During this time, gears and pointers were used in the design of clocks. These machine elements, and more especially a wheel which gave impetus to a second wheel at the end of a complete revolution, paved the way for the development of calculating machinery.

It was Blaise Pascal[1,2] who, in 1642, designed and built the first mechanical adding machine in the modern sense of the term. This machine depended upon the use of rotating wheels and provided for carry by mechanically turning the wheel of next higher order one position when the lower passed from nine to zero. The direct actuation of a numbered wheel and the secondary feature of effecting carry (which seem to have been used first in an adding machine by Pascal) are the foundation on which nearly all mechanical calculating machines since have been constructed.

Naturally, any machine designed for addition also may perform subtraction by means of complementary numbers. The complement on ten of a number is that second number which must be added to the first in order to obtain a power of ten. This complement on ten may be read off from left to right by taking the complement on nine of each successive digit except the last on the right, of which the complement on ten must be taken. Thus the complement on ten of 7,528 is 2,472. To subtract 7,528 from any number, for example 38,421, one may write

$$38,421-7,528=(38,421-10,000)+(10,000-7,528)=28,421+2,472=30,893$$

This procedure may be simplified further by the use of complements on nine and "end around carry."[3] End around carry implies carry from the highest column of a machine to the lowest column of the machine. The complement on nine of 7,528 in a 6-column machine is 992,471. Subtraction now becomes

$$038,421+992,471+000,001=030,893$$

where the third term, 000,001, is supplied by end around carry.

If any number, for example 007,364, is added to 999,999, operation of the machine will yield

$$999,999+007,364+000,001=007,364$$

where the third term is again the result of end around carry. Since, under these conditions, 999,999 is a number with the properties of minus zero for machine purposes, the complement on nine of any number may be adopted as the negative of the number. Clearly, an n digit calculating machine must be supplied with $(n+1)$

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Design and construction of the automatic sequence controlled calculator was begun in 1939 at Endicott, N. Y., and continued until August 1944, when the machine was presented formally to Harvard University by T. J. Watson, president, International Business Machines Corporation. Commander Aiken wishes to express his appreciation to Mr. Watson for the support of International Business Machines Corporation during the years of development of the calculator and further to B. M. Durfee, F. E. Hamilton, and C. D. Lake, who, together with Commander Aiken, were coinventers of the machine. The relays, counters, cam contacts, typewriters, card feeds, and card punch employed in the calculator are all standard parts of tabulating machinery as constructed by International Business Machines Corporation.

The opinions or assertions contained in this article are the private ones of the writers and are not to be construed as official or as reflecting the views of the Navy Department or the naval service at large. Material for the article has been adapted largely from "The Manual of Operation of the Automatic Sequence Controlled Calculator," *Annals* of the Computation Laboratory of Harvard University, volume I, Harvard University Press, Cambridge, Mass., 1946. Permission to use this material has been granted.

columns, the highest being reserved for the algebraic sign, and zero and nine being positive and negative respectively.

The next major development in mechanical aids to numerical computation was brought about in 1666 when Samuel Morland[4,5] built a machine similar to Pascal's, but which was adapted to multiplication by repeated

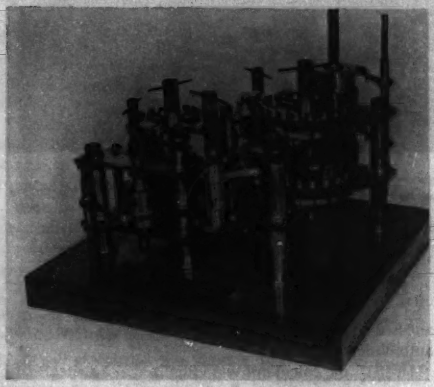

Figure 1. Calculating wheels designed by Babbage, 1834

addition. Independently, in 1671, Leibnitz[6,7,8] conceived a multiplying machine and finished it in 1694. In Pascal's machine the wheels were set and turned individually by hand; in Leibnitz' machine all wheels were set and turned simultaneously by a crank to a previously determined position. In the "stepped reckoner," Leibnitz added a device which still is used as a component part of modern calculating machines.

It was not until just before the beginning of the 19th century that any attempt was made to build highly specialized calculating machines designed for the mathematical and physical sciences. A Hessian military engineer, J. H. Müller,[9,10,11] seems to have had the first idea for a difference engine in 1786. But this idea remained in a purely theoretical state and undoubtedly was forgotten until, in 1812, it occurred to the philosopher, Charles Babbage, and he began the actual construction of such an engine.[12,13] Figure 1 shows a fragment of Babbage's difference engine, preserved in the Computation Laboratory of Harvard University in Cambridge, Mass. This engine was to "perform the whole operation (the computation and printing of tables of functions) without any mental attention when once the given numbers have been put into the machine."[14] A first model was built between 1820 and 1822 which consisted of six columns using second differences. In 1823, the construction of an engine using 26 significant digits and sixth differences was begun with the aid of a subvention from the British government. The construction continued until 1833 when government aid was withdrawn. The major part of the unfinished machine is preserved in the collections of the South Kensington Science Museum in London, England. It should be remembered that the difference engine, although a highly useful scientific instrument, was still a specialized machine intended solely for tabulating the values of a function for equidistant values of the argument.

THE ANALYTICAL ENGINE

In spite of being unable to complete the difference engine, Babbage embarked upon the creation of a far more ambitious concept, an "analytical engine."[13,16,17] Though the terms of the problem proposed were enough to stagger contemporary imagination, he attempted to design a machine capable of carrying out not just a single arithmetical operation, but whole series of such operations without the intervention of an operator. The numbers in the first part of the machine, called the "store," were to be operated upon by the second part of the machine, called the "mill." A succession of selected operations was to be executed mechanically at the command of a "sequence mechanism" (a term unknown to Babbage). For this latter mechanism, he intended to use a variation of the Jacquard cards.[18] These cards, the precursors of Hollerith's punched cards, were used by the Jacquard weavers to control their looms in order to produce and reproduce the patterns designed by the artists.

In the adaptation of these cards for use in his machine, Babbage required two decks: one of variable cards and one of operational cards. The first set was designed to select the particular numbers to be operated upon from the store; the second set, to select the operation to be performed by the mill. As the deck of operation cards represented the solution of a mathematical situation independent of the values of the parameters and variables involved, the analytical engine was to have been completely general in regard to algebraic operations.

As in the difference engine, the analytical engine was to print its own results. Further, a mechanism was to have been added for punching numerical results in blank cards for future use. In this way, the engine could compute the tables required and punch its own cards "entirely free from error."[19]

In 1906, H. P. Babbage, son of the philosopher, completed a part of the analytical engine. A table of multiples of π which it computed to 29 significant digits was published as a specimen of its work.[20] Clearly then, Babbage's failure to complete either of his projects himself was not due to a lack of understanding of the principles and purposes of the engines that he designed, but rather to his lack of machine tools, materials of construc-

Figure 2. Front view of calculator

Left—Adding storage registers
Center—Multiply-divide counter
Right—Typewriters

tion, and electrical circuits. Though his principles were theoretically sound, and though he was successful to a limited extent, it remained for the 20th century and the evolution of advanced mechanical and electrical engineering to bring his ideas into being.

INCREASED NEED FOR MECHANICAL COMPUTATION

It already has been indicated that the need for mechanical assistance in computation has been felt from the beginning of science. At the present time this need is even greater than before. The intensive development of mathematical and physical sciences in recent years has included the definition of many new and useful functions, nearly all of which are defined by infinite series or other infinite processes. Most of these are tabulated inadequately and their application to scientific problems is retarded thereby.

The increased accuracy of physical measurement has made necessary more accurate computation. Many of the most recent scientific developments are based on nonlinear effects. All too often the differential equations designed to represent these physical phenomena may be solved only by numerical integration. This method involves an enormous amount of computational labor. Many of the computational difficulties with which the physical and mathematical sciences are faced can be removed by the use of suitable automatic calculating machinery.

The development of numerical analysis (a bibliography may be found in the *Annals* of the Computation Laboratory, Harvard University),[21] including the techniques of numerical differentiation and integration, and methods for solving ordinary and partial differential equations have reduced, in effect, the processes of mathematical analysis to selected sequences of the five fundamental operations of arithmetic: addition, subtraction, multiplication, division, and reference to tables of previously computed results. The automatic sequence controlled calculator was designed to carry out any selected sequence of these operations under completely automatic control.

In 1937, the calculator was visualized as a switchboard on which were to be mounted various pieces of calculating machine apparatus, each panel of the machine being given over to definite mathematical operations. The completed machine, 51 feet long and 8 feet high (Figures 2 and 3) closely resembles the original description. It operates normally on 23 significant digits, but high accuracy computations have been carried to 46 significant digits. An automatic sequence mechanism governs the operation of the entire calculator which consists of 60 constant registers, 72 adding-storage registers, a central multiplying and dividing unit, and electromechanical tables of the elementary transcendental functions, $\log_{10} x$, 10^x, and $\sin x$. In addition, three interpolator units, reading functions coded in perforated paper tapes, perform interpolation of any order up to and including the 11th. Computed results may be recorded in tabulating machine cards for the interchange of data from one computation laboratory to another, or for use in further computation. Results also may be printed by means of two electric typewriters. All computations carried out by the calculator are checked automatically before the results are printed in final form.

The sequence and interpolator mechanisms and the counter wheels all are driven and synchronized by a single gear-connected mechanical system. In Figure 4, *A* is a line shaft extending nearly the full length of the calculator. It is driven by the 5-horsepower motor, *B*. This shaft is contained in the shaft housing shown near the base of the machine in Figures 2 and 3. The main sequence mechanism and the three interpolator mecha-

nisms are supplied with mechanical power by roller chain and sprocket drives, *C* and *D* respectively. The spiral gears, *E*, connect the main drive shaft to the vertical shafts, *F*. These in turn are connected to the horizontal shafts, *G*, through small spiral gears, *H*. On the shaft, *G*, are mounted 12 or fewer gear wheels (*J* of Figure 4) each of which supplies mechanical power to a single counter wheel by engaging with the gear shown in the partially assembled counter.

Figure 3. Front view of calculator showing sequence control mechanism (right of four black panels), heart of control, which tells machine what to do and when to do it

At extreme right are recording typewriters, card feeds, and card punch

Each counter wheel is an electromechanical assembly consisting of the following major components:

1. A stationary commutator mounted in a molded plastic part, commonly called a "molding," having a half slip ring and ten segmental contacts numbered 0 through 9.

2. A pair of stranded wire brushes, which rotate to connect one of the contact segments with the commutator half slip ring.

3. A magnetically controlled clutch, which engages to connect the continuously rotating gear with the sleeve on which the rotating brushes are mounted.

4. A ten's carry contact which operates in conjunction with an external relay circuit to provide carry to the counter wheel in the next higher columnar position when the counter wheel under consideration passes through ten.

5. A nine's carry contact which also operates in conjunction with an external relay circuit to provide carry to the next higher counter wheel when the wheel under consideration stands on nine and the next lower wheel has passed through ten.

6. Finally, a socket by which the counter assembly may be jack-connected to the calculator wiring.

The ten segments of the commutator usually are called the number "spots." The time interval necessary for the brush to traverse the distance between two successive spots is 1/16 of a cycle, the number spots being so spaced in the commutator as to minimize the ratio of the mechanical backlash to the distance traversed between spots. In order to read, for example, a seven into a counter, the counter magnet is picked up at "seven time," thus engaging the clutch. The brushes are spun past six spots and the clutch is disengaged mechanically or knocked off at "zero time." Obviously, nine equally timed and equally spaced impulses must be provided to pick up the counter magnets in order to read in the nine digits and all counters must be knocked off at zero time.

The number impulses are supplied by cam-controlled contacts. The position in which the cams are mounted is shown in Figure 4, *K*. The duration of the contact controlled by a cam may be varied by adding or subtracting rollers in the 20 possible sockets in a cam wheel. Several types of followers are used, with variations in the sharpness of the make and break of the contacts they control.

For purposes of cam timing, the fundamental cycle of the calculator, 300 milliseconds, is subdivided into 16 equal parts commonly referred to as "points." The first nine subdivisions contain the number impulses. The so-called "seven impulse," for example, is delivered by a cam contact making at seven time and breaking half way between seven and six time, commonly called $7^1/_2$ time. The points zero through 16 are available to supply carry and other control impulses.

The transfer of a quantity to a reset, or cleared, counter and the process of addition are the same. For instance, a counter stands at zero, a seven impulse picks up the counter magnet at seven time, the counter wheel rotates through six positions, is knocked off mechanically at zero time, and comes to rest standing on the seven spot. On the other hand, if a counter stands at five, a seven impulse picks up the counter magnet at seven time, the counter wheel rotates through six positions, is knocked off mechanically at zero time, and comes to rest standing on the two spot, having passed through zero.

As the counter wheel turns, the carry cam also turns. When the rotating brush touches the nine spot, the follower of the carry cam is dropped and the nine's carry contact is made. As the counter wheel passes nine and approaches the zero spot, the follower is raised and the ten's carry contact is made. The ten's carry contact once made is maintained until a mechanical knockoff returns the carry contact to neutral position at $14^1/_2$ time. The counter magnet again is

picked up at 12 time by the carry impulse if the carry relay circuits are closed and if the ten's carry contact of the next lower counter is made. The counter magnet also is picked up at 12 time by the carry impulse if the carry relay circuits are closed and if the nine's carry contacts of the succeeding lower counters receive a carry impulse due to a still lower ten's carry. The counter wheel moves one position for the carry and again is knocked off mechanically at 13 time.

The relays in the calculator are of a standard type of which six varieties are employed, 4, 6, and 12 pole, double throw, single or double coil. When a double coil relay is used, one coil serves for pickup, the other for hold. When it is required that more than 12 poles operate simultaneously, a number of relays are wired in parallel as a "bank."

THE SEQUENCE CONTROL UNIT

The sequence control unit, shown in Figure 5, consists of a main drive sprocket drum over which runs a perforated paper tape, called a control tape, together with such gears, cams, and clutches as are necessary to advance the drum and tape one line of perforations at a time. The sequence unit is equipped with a set of 24 sensing pins, controlled by a crosshead, which are advanced at the end of each forward step of the tape to detect the distribution of holes in one line of the tape and to close electrical contacts in the same distribution.

Each horizontal line of the tape has space for 24 equidistant holes which are considered as three groups of eight holes each, known as the *A*, *B*, and *C* groups. The *A* group of holes controls the "out-relays" by means of which all units in the machine are connected to the central distribution bus over which numbers are transferred from one unit to another with the aid of the number impulses. The *B* group of holes controls the "in-relays" of all of the units in the machine. These also connect the units to the central distribution bus, and, when closed, permit the egress of numbers from the bus into the units. Finally, the *C* group of holes represents, in general, an operation to be performed on the number in unit *A* in connection with the number in unit *B*.

Each horizontal line of holes perforated in the tape is the equivalent of a single spoken command, "Take the number out of unit *A;* deliver it to unit *B;* start operation *C*." Since the *A*, *B*, and *C* groups of perforations each contain eight holes, the maximum number of out, in, or operational relays which can be controlled by the machine is $2^8 = 256$ each. The maximum possible number of commands which can be represented by a single line of holes is $2^{24} = (256)^3 = 16{,}777{,}216$. The number of combinations of coded perforations in use at present is considerably smaller than the maximum possible number. However, the number of consecutive lines of holes in no way is limited and it is apparent that control tapes may be provided with great generality. The reiteration of the single command, "Take the number out of unit *A;* deliver it to unit *B;* start operation *C*," permuting *A* and *B* over the various units of the machine while changing the nature of the operation *C*, is sufficient to guide the machine through any mathematical problem capable of being reduced to the five fundamental operations of numerical analysis.

At the left of the machine, as well as at the left of Figure 6, are the 60 constant registers. Each constant register consists of 24 manually set 10-pole dial switches

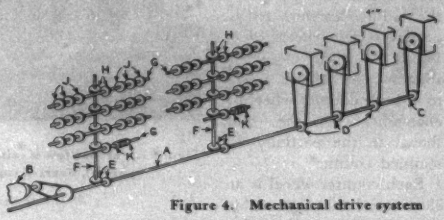

Figure 4. Mechanical drive system

designed to accommodate 23 digits and the algebraic sign. Because of their composition, the constant registers are known as the 60 "switches." Each constant register or switch is connected to the bus through its out-relay, and each is connected to the common transfer terminal of the storage register invert relay. The normally closed and normally open contacts of this relay are connected in turn to the direct and invert cam-controlled contacts, respectively, which furnish the timed electric impulses necessary to the transfer of numbers by way of the bus.

To the right of the switches, Figure 6, are shown diagrammatically the 72 storage registers. Each storage register consists of 24 electromechanical counter wheels. The storage registers, usually referred to as "storage counters" or more briefly as "counters," have electrical circuits similar to those of the switches. In addition, each storage counter is provided with an in-relay connected to the bus, a complete set of carry controls, and a connection to the negative terminal of the generator.

Each register in the calculator is provided with a code number corresponding to the numbers of the holes perforated in the tape. The code numbers of the storage counters, 1, 2, 3, . . . , 71, 72, which may appear in either the *A* or the *B* column, are 1, 2, 21. . . . , 7321, 74, respectively, while the code numbers of the switches, 1, 2, 3, . . . , 59, 60, which may appear in the *A* column only, are 741, 742, 7421, . . . , 821, 83, respectively. Similarly, all operations in the calculator have assigned code numbers. For example, code 32 in the *C* group of perforations controls the storage counter invert relay, and hence is the mathematical equivalent of a minus sign.

Now let it be required that the number x in storage counter 3, code 21, be added to the number y in storage counter 71, code 7321. This requires that holes 2 and 1

be punched in the *A* column and holes 7, 3, 2, and 1 in the *B* column. The line of coding thus may be written (21, 7321, blank). On the other hand, if it is required that *x* be subtracted from *y*, the line of coding will be written (21, 7321, 32), indicating that by means of the invert relay the nines complement of the quantity *x* in counter 3 is to be added into counter 71.

Referring again to Figure 6, the perforations in the control tape corresponding to code 21 in the *A* column, as interpreted by the sequence mechanism, cause the closure of the out-relay of counter 3, while the code 7321 in the *B* column causes the closure of the in-relay of counter 71. The blank in the *C* column of the coding is interpreted as a plus sign leaving the storage counter invert relay in its normally closed position. A complete electrical circuit exists beginning at the positive terminal of the generator, passing through the cam contacts, through the normally closed contacts of the storage counter invert relay into counter 3, through counter 3 and its out-relay to the bus, from the bus to counter 71 through its in-relay, through counter 71, and finally back to the negative terminal of the generator. Thus, the number impulses produced by the cam contacts are able to transfer the quantity in counter 3 to counter 71 and bring about addition.

When it is necessary to subtract *x* from *y*, the whole operation is the same except that code 32 in the *C* column causes the storage counter invert relay to transfer its contacts. This causes the complement on nine of *x* to be read out into the bus instead of *x* itself. As all storage counters are equipped with complete carry controls, including end around carry, addition of the complement on nine completes the process of subtraction as demanded in the example.

Before further considering the functions of the storage counters, it is necessary to discuss briefly the means by

Figure 5. Closeup view of sequence control mechanism

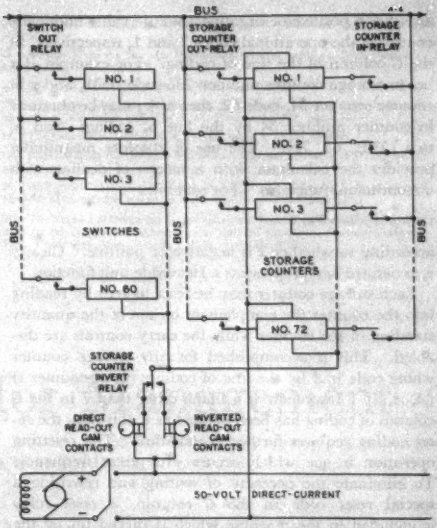

Figure 6. Switches and storage counters

which the calculator is kept in continuous operation. Most mechanisms, once started, remain in operation until signaled to stop. By contrast, the calculator continues in operation only as long as the command "continue operation" is repeated, cycle by cycle, and immediately stops when this command is not given. A 7 in the *C* column of a line of coding instructs the sequence mechanism to continue operation; that is, to read the next line, act upon it, and step to the line beyond. Every line of coding must contain a 7 in the *C* column or its equivalent in the form of some other automatic continue operation code. As the storage counter codes are not such "automatic codes," the two examples of coding already cited should read: take *x* from counter 3 and add it to *y* in counter 71 (21, 7321, 7); take *x* from counter 3 and subtract it from *y* in counter 71 (21, 7321, 732).

THE STORAGE COUNTERS

From what has been discussed thus far it should be clear that storage counters serve more than one purpose. Each is a complete adding and subtracting machine, and functions as a storage or memory device, thereby providing the calculator with brackets, parentheses, and other signs of association as required in mathematical expressions. In addition, relays associated with each counter provide other functions not indicated in the single line diagram, Figure 6, for purposes of clarity.

The quantity in each storage counter may be read out

as either a positive or negative absolute value under the control of the operational codes 2 and 1, respectively, in the C column of the line of coding. For example, if x lies in storage counter number 23, code 5321, and y in counter number 34, code 62, then $|x|+y$ may be obtained in counter number 34 by the line of coding: add $|x|$ to y (5321, 62, 72). The use of absolute magnitudes provides the calculator with a means of dealing with discontinuous functions. For example:

$$\gamma=(x+|x|)/2x=0 \text{ or } 1$$

according to whether x is negative or positive. Clearly γ, as defined here, represents a Heaviside unit function.

Each storage counter may be reset to zero by reading into the counter the complement on ten of the quantity standing in the counter while the carry controls are disabled. This is accomplished for any storage counter whose code is A by the line of coding: reset counter A (A, A, 7). Inasmuch as a blank other than 7 in the C column of coding has been defined as a plus sign, the reset coding requires further explanation. The resetting operation is one which occurs with great frequency. To eliminate the necessity of writing and rewriting a special reset code in the C column, a reset relay is included in the machine which is picked up by the duplication of a storage counter code in both the A and B columns of a line of coding. The reset relay provides the complements on ten to reset the counter concerned.

Of all the computing elements in the calculator, the storage counters are the simplest. It is relatively easy to alter and to add to their electrical circuits in a way which will not interfere with their normal functioning but, at the same time, will introduce added possible operations. A number of such special operations have been required in the past and were built into the machine permanently.

Counter 70 has been equipped with relay circuits which prefix the algebraic sign of the quantity in counter 70 to the positive absolute value of the quantity standing in any other storage counter when the latter is read out under code 432 in the C column. This feature is especially valuable when dealing with the interpolation of odd functions, since it is only necessary to evaluate $f(x)$ in order to have available $f(-x) = -f(x)$.

Associated with counter 71, the "multiple in–out" counter, is a special set of carry controls which make a 12-column storage register out of the 12 high order columns of the counter. This 12-column counter is complete with end around carry, can be reset independently, and does not interfere in any way with the normal 24-column functioning of counter 71. The multiple in–out counter has extra in and out relays which connect the upper 12 columns of the counter to either the upper or the lower 12 columns of the bus. Mathematically, this is the equivalent of multiplying by 1 or 10^{12} when numbers are read into the counter and by 1 or 10^{-12} when numbers are read out of the counter, depending upon the codes employed. In all problems requiring less than 12 significant digits for computation, the transfer of numbers through counter 71 permits the storage of two quantities in each of the 72 storage counters, thus doubling the storage capacity of the machine. The function of the multiple in–out counter is most valuable in statistical computation where the quantities dealt with are large in number and of low accuracy.

THE "GANGED COUNTERS"

Just as the multiple in–out counter doubles the storage capacity of the calculator at the expense of accuracy, the "ganged counters," 68 and 69, double the accuracy of the machine at the expense of storage capacity. Counters 68 and 69 are equipped with special carry controls so that they function as a single storage register consisting of 46 columns and the algebraic sign which is repeated in the two component counters. As this feature has proved to be of considerable value in high accuracy computation, particularly in the computation of the Bessel functions, counters 64 and 65 likewise have been ganged together. Needless to say, the inclusion of the special carry controls on counters 64, 65, 68, and 69 do not interfere with their normal functions. Two lines of coding are required to make a single 46 column addition, since the two parts of the number must be added successively. An 8 prefixed to the ordinary read-in codes of the ganged counters picks up the special carry controls. The addition of $A+B$, a 46-column quantity lying in counters 35 and 34, codes 621 and 62, to $C+D$, standing in counters 69 and 68, codes 731 and 73, is coded as: add $A+B$ to $C+D$ with special carry controls (621, 8731, 7), (62, 873, 7).

The most important of the specialized storage registers is the automatic check counter, 72. In general, all checks may be reduced to determining that a given quantity, ϵ, is less in absolute magnitude than a selected positive tolerance, t; that is, that $t-|\epsilon|>0$. The use of the check counter is based upon the notion that this inequality will be evaluated in counter 72. Obviously, an end around carry will occur when $-|\epsilon|$ is added to t, if, and only if, the inequality holds. The coding for the check procedure is: check the quantity in counter C against the positive tolerance in switch or counter T (T, 74, 7), (C, 74, 71), (blank, blank, 64), where code 64 is an automatic continue operation code if, and only if, an end around carry takes place in the check counter. If $t-|\epsilon|\leq 0$, no end around carry will take place, the machine will receive no command to continue operation and so will stop.

Parts II and III of this article will appear in subsequent issues.

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Quality Reports for Management

MARTIN A. BRUMBAUGH

THIS SUBJECT presupposes that a quality control operator has been at work in a plant and has obtained some results that are worth reporting. In making such a report he must recognize that there exists a great variety of:

1. Types of plant operations.
2. Points of view of quality control operators.
3. Attitudes of management.

Each of these factors must be taken into account in planning a reporting program. Accordingly what follows here must be interpreted in terms of conditions existing in a particular plant. In general, a quality control operator earns his salary by possessing two types of ability: a knowledge of where to find things in a book, and a knowledge of when to abandon the book in favor of his own ingenuity.

The operator who is in the fortunate position of working with management that understands the technique of statistical control can report in detail everything that he is doing. In fact, keeping management fully informed is the best method of maintaining interest in the work.

The author has witnessed the successful use of the following three entirely different methods of reporting to a management that was uninformed on statistical control. There must be others that have been used with equal success.

War experience brought to the fore the desirability of statistical quality control and today an increasing number of industrial concerns are utilizing this method of improving the processes of manufacture. However, many firms, notably smaller establishments, still are not employing quality reports when they could do so to advantage. This article emphasizes the necessity of making management quality-control conscious and cites actual cases to prove its point.

1. The probability approach: set up examples with cards, dice, or colored beads to show chance variability; plan the experiments so that they will be applicable to the plant's manufacturing operations.

2. The control chart approach: tell the story of separating chance variability from assignable causes of variability; show the frequency distribution analysis and application to plant operations; present the principles of sampling, preferably with examples of potential or actual savings.

3. The indirect approach: forget statistical control and tell the story solely in terms of operations and results obtained; bring in the control chart as an operating device and keep the statistical background out of the presentation.

If management is hostile, or even only lukewarm, great care is required. In the belief that this situation requires the greatest amount of discussion, two cases are presented in the sequel in which quality control operators succeeded in converting hostile managements.

CASE I

The quality control engineer operated two levels below the quality manager who reported directly to the plant superintendent, the responsible policy-making

Essential substance of a conference paper presented at the AIEE winter convention New York, N. Y., January 21–25, 1946.

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executive. Initially the quality control engineer was authorized by his supervisor to analyze records of inspection of assembly operations. The engineer prepared charts of number of defects per unit and posted them at all assembly stations. Simultaneously he inaugurated a system of weekly reports. These reports were circulated to foremen of inspection and production as well as to the quality manager and the plant superintendent. There was no evidence that the executive paid the slightest attention, but the quality of assembly work improved steadily.

At the end of three months the engineer submitted a report which included Table I. This table finally attracted the plant superintendent's attention and he ordered an expansion of the statistical department with instructions to investigate fabrication operations and receiving inspection.

The machine shop, although producing 400,000 piece parts per week, was characterized by short runs, sometimes making as many as 800 different part numbers in one week. Control chart analysis of an operation of this type was not attempted, even though the initial record of 15 per cent reworked and 4 per cent scrapped indicated plenty of room for improvement. Instead, a weekly report of the form shown in Table II was circulated to management and to shop supervision. Just as in the assembly area, this report received scant attention and for several weeks no improvement was shown. A chronic rework was defined as an item for which at least 10 per cent of production was returned to the machine shop for at least three successive weeks. This supplementary information finally caught the eye of the plant superintendent and action followed quickly. Individual foremen were called in for specific explanations. The usual attempt to "pass-the-buck" was stopped short by the detailed inspection records presented by the control engineer. Corrective action was swift and permanent. The results after seven months of reporting are apparent in Tables II and III.

A report to the plant superintendent stressed the fact that in 1944 one piece out of six passing through the shop and passing to the inspection bench was covering the route a second time. Stated differently, this meant that one-sixth of the machine capacity of the shop was ineffective and that inspection costs were inflated by 20 per cent. This situation was corrected automatically by the reduction in reworks in 1945 This report was made to offset the shop supervision contention that reworks were inexpensive.

A parallel reporting procedure was set up for receiving inspection, but its effect was negligible until the control engineer prepared a vendor rating sheet and submitted it to the purchasing department. This sheet is shown as Table IV, with individual part numbers and vendors listed. The first one was made for a list of standard parts. Subsequent ones were made for the list of special parts going into a single subassembly. Purchasing discovered the parts for which a particular vendor could maintain good quality, as well as the vendor or vendors that could maintain good quality on a particular part number. A supplementary sheet showing the number of rejected lots during the month returned to each vendor, quickly revealed the source of most of the costly follow-up work of the purchasing department. On the basis of this rating sheet the purchasing department rearranged its contracts, assigning to each vendor the part numbers which that vendor could do best. A few vendors with uniformly poor quality records were dropped. The effect of this rearrangement was apparent on the rating sheets of subsequent months.

The reports described are only a sample of the work done by this control engineer. He adhered to the point

Table I. Man-Hours Per Unit in Assembly Before and After Using Statistical Control

Item	November December January (Man-Hours Per unit)	February March April (Man-Hours Per unit)
Assembly	3,240	3,328
Inspection	733	766
Repair and replacement	1,209	405
Reinspection	290	56
Total	5,472	4,555
Number of units accepted by United States Army	367	508

Table II. Quality of Production in Machine Shop Before and After Corrective Action

Status	Number of Pieces Through Inspection Week Ending		Per Cent of Total Pieces Inspected Week Ending		Average Per Cent for Previous Ten Weeks Week Ending	
	August 19, 1944	March 24, 1945	August 19,1944	March 24,1945	August 19,1944	March 24,1945
Accepted as is	332,518	218,706	83.7	97.1	85.2	97.5
Not accepted as is	64,757	6,474	16.3	2.9	14.8	2.5
Total	397,275	225,180				

Table III. Analysis of Rejected Pieces

From Table II

Reason for Return to Machine Shop	Number of Pieces Week Ending		Per Cent of Total Pieces Inspected Week Ending	
	August 19, 1944	March 24, 1945	August 19, 1944	March 24 1945
Operations omitted	23,320	712	5.62	0.32
Rework dimensions	15,338	1,562	3.86	0.69
Burrs	10,159	46	2.53	0.02
Rechase threads	8,311	132	2.09	0.06
Strip chrome	1,182	496	0.30	0.22
Heat treat	1,343	18	0.34	0.01
Miscellaneous	714	538	0.18	0.24
Scrapped	15,230	2,998	3.83	1.33
Total	75,597*	6,502*		

* Higher total due to multiple defects.

Table IV. Vendor Rating Sheet

Average Per Cent Defective of Inspected Samples or Lots

Name of Vendor	Part Number 1	2	3	4	5	6
A		0.02		0.02	0	
B						0.05
C	0.08	0	0.03			0.01
D				0.11		0
E			0.03	0.04		
F		0.10		0.07		

of view that corrective action should be the responsibility of production, but that it was his task to provide as much detailed information as possible to aid production. He made no spectacular attempts to attract the attention of top management, but rather depended upon the cumulative effect of repetitive reporting. He did come to three conclusions:

1. Immediate superiors with no knowledge of quality control procedure and no desire to acquire such knowledge are a hindrance to progress despite good intentions.

2. Top management must possess some knowledge of quality control procedure and a genuine interest in using control results as a management tool, if the work of the control engineer is to be effective.

3. There is no method of evaluating or reporting the intangible gains from the use of statistical control; hence evaluated dollar savings are always an underestimate of the benefits of a control system.

CASE II

The chief inspector of this plant reported directly to the factory manager and within his own function possessed sufficient authority to introduce statistical control procedure as an integral part of inspection operations. This was done initially in the assembly area because this plant does comparatively little fabrication, although many special parts are machined in the plant.

Over a span of three months considerable improvement in assembly operations resulted from daily and weekly reporting of the results of inspection. When out-of-control conditions were encountered, immediate investigation followed. In some cases this led directly to receiving inspection. Detection of quality variation there led in several cases to the dispatch of trouble shooters to plants of vendors. In other cases assembly failures quickly were traceable to faulty machine shop operations. In still other cases it was found that piece parts and subassemblies were being damaged during assembly. In a few cases blueprints were changed on the basis of the control chart records. Corrective action produced results which were recognized by operating supervision throughout the plant, but top management gave no evidence of being aware of the existence of the quality control system until the chief inspector prepared a summary in the form shown in Table V.

Table V. Status of Assembly Operations After Three Months of Corrective Action Based on Control Chart Records

Assembly Operation	Per Cent Defective: At Start of Program	One Month Later	Two Months Later	Three Months Later	Per Cent Improvement in Three Months
A	6.2	5.1	4.1	2.3	63
B	36.0	22.9	13.5	10.4	71
C	11.2	6.6	4.9	1.7	85
D	10.7	8.2	3.4	2.5	77
E	69.6	65.8	61.5	45.8	34
F	18.8	12.3	11.3	10.6	44
G	6.3	4.2	2.6	1.5	76
H	7.2	5.1	3.9	2.9	60
I	15.3	9.7	5.2	4.6	70
J	10.1	3.9	2.7	1.6	84
K	26.9	16.1	12.7	9.1	66
L	2.7	1.1	0.3	0.4	85

This report produced ample response from top management, and the chief inspector was authorized to install statistical control of all operations in the plant. The chief inspector is very meticulous about placing on the president's desk periodic summary reports of the quality status of all operations.

In passing, several other experiences can be mentioned briefly. A quality manager planning the introduction of statistical control "sold" the idea to top management and secured a general directive authorizing him to install his system. He then began issuing orders to operating departments, but did not train men in his own inspection department in control chart technique or corrective action procedure. Needless to add that the results were disastrous. This man shortly was transferred to another plant and soon left the company.

In another plant a new vice-president in charge of plant operations announced that all emphasis must be placed on two departments—production and selling. Pursuant of this plan, the inspection department was skeletonized and a flourishing statistical control installation was abandoned. Three months of this policy resulted in the loss of a long-standing contract to make an important subassembly for a large automobile manufacturer.

SUMMARY

Because conditions vary so greatly from plant to plant, there is little possibility that any usable rules can be stated for reporting quality control results to management. The following, which are little better than guesses, may have some guidance value:

1. Present summaries, not details.

2. Make it simple, but be sure to tell the story.

3. Dollar savings are most effective, but dollar figures often breed controversy. Perhaps a man-hour report will serve better than a dollar report.

4. Modesty is essential, over-modesty may be fatal.

5. No harm will come from allowing a small amount of residual mystery to inhere in the expression, "statistical control."

6. Concrete results will attract attention; do not waste an executive's time with reports of pious hopes.

INSTITUTE ACTIVITIES

Some Jobs to Be Done—*A Message From the President*

As a matter to which some special attention should be given during the 63rd year of our AIEE activities, I wish to bring to your attention the problem of the industrial electrical engineer, a problem with which I have been struggling for some 30 years. The Institute has done a great deal for the industrial electrical engineer, but our field of industrial activity has expanded so greatly that we now need to make special efforts to cover that field adequately. Rather than to default in our opportunity, and allow the industrial electrical engineers to branch out into a separate organization, as others have done in the past, let us *do* something *now* to serve the needs of this particular group. The AIEE local Sections are in the best position to do something about this matter. They are close to the industrial areas, and I believe that they could determine very readily the peculiar problems, needs, and interests of the industrial groups.

Particularly, aside from the purely technical phases of the problem, I should like to emphasize the desirability of getting together and rubbing elbows with the industrial engineers. Too many of us are inclined to think that this group has been graduated too recently from the screwdriver-and-pliers class to deserve much attention. Quite to the contrary, the complexity of the apparatus and circuit for which industrial engineers are responsible, demands considerable talent, even from the research and scientific fields.

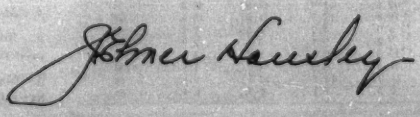
I urge the Sections committee to encourage meetings between the power systems engineers and the engineers in industrial plants. In the textile mills of the South, some progress has been made in this very direction, and the common contact has been found to be mutually beneficial. It should be extended. In the more densely settled industrial areas, such meetings already have been established. Where the territory is spread thin, and one AIEE Section covers an entire state, it may be possible for these Sections to arrange for speakers to travel to some of the smaller industrial towns, and there put on programs of industrial interest. I believe that this would be beneficial, even though the initial attendance at such meetings might be relatively small. Perhaps the Sections committee might do well to study the use of wire sound recorders and transcriptions, and radio programs or film, such as the sales departments of various companies have used so effectively.

Another example of what I have in mind is represented by the special report, "Electric Power Distribution for Industrial Plants," developed by our committee on industrial power applications. I believe that this excellent report should be called to the attention of a large number of the key industrial engineers who are not members of the Institute, as a means of introducing them to AIEE activities. The industrial field is wide open, and the surface has not yet been scratched so far as membership possibilities are concerned; continued industrial expansion gives us an opportunity to share AIEE benefits with the engineers of industrial plants.

Another opportunity for intimate contact and discussion of common problems with industrial engineers lies in the technical groups that have been developed by many of our Sections, and which are so deservedly popular. I hope that this idea will continue to expand. Particularly, I consider it to be especially desirable that more industrial groups such as electronics, instruments and measurements, and perhaps refresher courses in industrial or other technical subjects, be established and actively operated by our Sections.

Especially do I urge our Sections to undertake to bring research men and manufacturing engineers closer together on a basis of common understanding; to establish a closer and better working relationship between our Sections and our Student Branches, particularly with reference to the matter of training men specifically for the very important field of industrial plant operation; to establish study and discussion groups on economic problems, and on employer–employee relations as they involve the engineer; to extend the range of Section co-operative efforts with other engineering groups and local councils on problems of common interest and contemporary importance; and to promote the growth and development of Subsections, especially in areas with scattered industrial installations.

Without challenging the need of the basic technical data which the AIEE has been accumulating over the years, I believe that it is necessary also to recognize the problems of the user of electric equipment. There are many startling things encountered in the application and operation of equipment, that could not possibly have been anticipated by the designer; discussion of these would be helpful to the designer, the researcher, and the user.



AIEE Pacific Coast Meeting, Seattle, Wash., August 27–30, 1946

Tuesday, August 27

9:00 a.m. Opening Session

C. F. Terrell, presiding

Address: Development of Atomic Power. **Bruce R. Prentice**, General Electric Company

46-178. Power System Development for Service to Hanford Plutonium Plant. **B. V. Hoard, J. R. Curtis**, Bonneville Power Administration

46-185—ACO.* Columbia River Power. **E. I. Pease, H. W. Goodhue**, United States Engineer Office, Seattle

2:00 p.m. Central Stations

Thomas Ingledew, presiding

46-184. Specific Engineering Problems in Rural Electrification and Electroagriculture. **M. M. Samuels**, Rural Electrification Administration

46-201—ACO.* Hydroelectric Power System Design. **S. M. Denton**, United States Department of the Interior, Denver

46-191—ACO.* Design Factors to Promote Reliability of Hydroelectric Station Auxiliaries. **C. L. Kilgore**, United States Department of the Interior, Denver

46-177. 4,370,000-Kva Short-Circuit Tests on Grand Coulee 230-Kv Bus. **W. H. Clagett**, United States Bureau of Reclamation; **W. M. Leeds**, Westinghouse Electric Corporation

46-195. The Use of Business Machines in Determining the Distribution of Load and Reactive Components in Power Line Networks. **P. D. Jennings, G. E. Quinan**, Puget Sound Power and Light Company

Wednesday, August 28

9:00 a.m. Industrial and Railroad

W. C. Smith, presiding

46-186. Comparisons of Railway Motive Power for Operation in the Pacific Northwest. **T. M. C. Martin**, Bonneville Power Administration

46-91. High-Voltage Ignitron Rectifiers and Inverters for Railway Service. **J. L. Boyer, C. G. Hagensick**, Westinghouse Electric Corporation

CP.** A New D-C Control for Cargo Handling. **S. Rifkin, W. R. Morton**, General Electric Company

46-179. Fault-Current Measuring Device. **M. J. Lantz**, Bonneville Power Administration

46-187. Teaching Electricity and Magnetism. **V. P. Hessler**, University of Kansas

46-194. Self-Excited Electromagnetic Drive for a Resonant Fatigue Machine. **A. R. Willson**, Boeing Aircraft Company

2:00 p.m. Student Session

E. W. Schilling, presiding

Carrier Current through Power Distribution Networks. **V. Clayton, E. Jones**, University of Utah

Railway Signaling. **F. Curry**, University of Arizona

● PAMPHLET reproductions of authors' manuscripts of the numbered papers listed in the program may be obtained as noted in the following paragraphs.

● ABSTRACTS of most papers appear on pages 411–13 of this issue.

● PRICES and instructions for procuring advance copies of these papers accompany the abstracts. Only numbered papers are available in pamphlet form.

● COUPON books in five-dollar denominations are available for those who may wish this convenient form of remittance.

● THE PAPERS regularly approved by the technical program committee ultimately will be published in "Transactions"; many will appear in "Electrical Engineering."

Operation of an Electronically Controlled D-C Motor. **R. Angell**, University of Idaho

Reconnection of an Induction Motor for Different Speeds. **G. D. Cowles**, University of Southern California

Electronically Controlled Circuit Breaker. **W. R. Aiken**, University of California

Thursday, August 29

9:00 a.m. Aviation

F. F. Evenson, presiding

Address: Military Aviation

46-193. Effects of Thermal Characteristics of Aircraft Generators on Load Analysis. **Stanley Rogers**, Consolidated Vultee Aircraft Corporation

46-190. Electrical Anti-Icing of Aircraft Windshields. **J. D. McCrumm**, Douglas Aircraft Company, Inc.

46-188. An Electronic Meter and Speed Regulator. **Ellis Levin**, Boeing Aircraft Company

46-197. 150,000 Horsepower Applied to Aeronautical Research. **J. A. White**, National Advisory Committee for Aeronautics

46-180. Control and Protection of Aircraft D-C Power Systems. **B. O. Austin**, Westinghouse Electric Corporation

46-192. An Improved Azimuth Indicating System for Aircraft. **E. E. Lynch, R. A. Pfuntner**, General Electric Company

2:00 p.m. Power Systems

E. A. Loew, presiding

46-189. Dielectric Strength of Station and Line Insulation to Switching Surges. **P. L. Bellaschi, L. B. Rademacher**, Westinghouse Electric Corporation

46-182. Long-Distance Power Transmission As Influenced by Excitation Systems. **C. Concordia, S. B. Crary, F. J. Maginnis**, General Electric Company

46-181. An Oscillograph for Recording Transient Recovery Voltages. **W. G. Hoover**, Stanford University

46-200. Sensitive Ground Relay Protection for Complex Distribution Circuits. **L. F. Hunt**, Southern California Edison Company, Inc.

46-196. Characteristics of a 400-Mile 230-Kv Series-Capacitor-Compensated Transmission System. **B. V. Hoard**, Bonneville Power Administration

Friday, August 30

9:00 a.m. Discussion on Organization of the Engineering Profession

C. B. Carpenter and **J. F. Fairman**, presiding

As has been done in other sections of the country, this session has been arranged to afford members in the Pacific Coast region an opportunity to participate in a discussion of the several projects under consideration by the Institute's committee on planning and coordination. It is hoped that members who plan to attend will review and discuss among themselves in advance the information about the activities of the committee on planning and co-ordination, which has been published in recent issues of *Electrical Engineering*. In particular, a lively discussion from the floor is anticipated about the respective merits of the four plans of organization of the engineering profession, outlined in the progress report of the professional activities subcommittee, which appeared in *Electrical Engineering*, April 1946, pages 169–73. The views of a representative cross section of the members in the Pacific Coast region about these important matters will be most helpful to the committee in its work.

2:00 p.m. Communications

F. O. McMillan, presiding

46-198—ACO.* Television—A Review of Present Status. **K. W. Engstrom, R. D. Kell**, Radio Corporation of America

46-183. Application of Compandors to Telephone Circuits. **C. W. Carter, Jr., A. C. Dickieson, D. Mitchell**, Bell Telephone Laboratories, Inc.

46-199. Field Tests of Power Line Carrier Current Equipment. **R. H. Miller**, Pacific Gas and Electric Company; **E. S. Prud'homme**, General Electric Company

CP.** Four-Tone Dual Channel Carrier Shift Telegraph System. **F. J. Werthmann**, Werthmann Radio Company

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*ACO: Advance copies only available; not intended for publication in *Transactions*.

**CP: Conference paper, no advance copies are available; not intended for publication in *Transactions*.

Summer Convention Held in Detroit for Third Time

With a verified registration totaling 1,351, the 61st annual summer convention of the AIEE set a new record for recent years, exceeded only by the 1923 summer convention at Swampscott, Mass., for which the reported registration was 1,616. The 1946 convention was held in Detroit, Mich., June 24–28, inclusive, with headquarters at the Hotel Statler. A heavy program of meetings, technical sessions, and conferences kept the members too busy to take full advantage of the recreational and inspection trip features arranged by the local committee. A continuous program of special events arranged by the local women's committee occupied the many women guests of the convention all week.

The formal program provided 19 technical sessions, 7 technical conferences, 8 administrative conferences, and 23 committee meetings, in addition to which several groups met impromptu for the discussion of special problems. The program provided for the presentation and discussion of some 75 technical program papers, 25 informal conference papers or presentations, and a huge number of special conference topics. The heavy and rigorous program evoked considerable casual comment, some approving a full and diversified program as a means of better service and appeal to a wider range of members, some urging strongly that, at least for the summer conventions, most of the formal meetings should be confined to morning schedules, leaving afternoons open for inspection trips, recreation, and other special features.

All of the technical sessions and most of the meetings and conferences were held in the headquarters hotel, but some of the administrative conferences and many of the committee meetings were accommodated at other hotels, the Rackham Memorial headquarters of the Engineering Society of Detroit, the offices of the Michigan Bell Telephone Company, and the offices of the Detroit Edison Company.

ANNUAL BUSINESS MEETING

The official annual business meeting of the Institute was called to order at 10 o'clock Wednesday morning, June 26, 1946, in the Wayne Room of the Hotel Statler, Detroit, by President W. E. Wickenden (F '39).

SECRETARY ABSTRACTS BOARD REPORT

Secretary H. H. Henline (F '43) invited the special attention of delegates and members to the detailed annual report of the board of directors, which was distributed at the meeting in pamphlet form and which was published in full in *Electrical Engineering* for July (*pp 331–50*). Special mention was made of the large number of Section visits made by President Wickenden, the active resumption of District meetings and conventions following the close of the war, and to the vitality and extended nature of Section activity; as well as to the important work of the technical program committee, the publication committee, the committee on planning and co-ordination, and other general and technical committees. These subjects are covered in the board report.

Mr. Henline reported that: "Membership had grown by April 30, 1946, to 25,090 . . . by June 2, to 25,218 . . . a net gain for the past fiscal year of 2,018, the largest for any year in the history of the Institute." He reported that Student Branch activities were being reactivated rapidly, following a severe wartime shrinkage; that "before the war, about 50 per cent of the applicants for Institute membership were the student members coming in as Associates; in recent war years that percentage fell to about 11."

As indicative of the extent to which opportunities for more active participation are being brought within the convenient reach of more members, Secretary Henline reported that 1,187 Section meetings were held during the fiscal year just closed, as compared with 747 for the preceding year; that the average number of meetings per Section had increased to 15.8 per year; the number of Section technical groups jumped from 155 to 195; and the number of Subsections from 12 to 20.

TREASURER SUMMARIZES FINANCES

Treasurer Walter I. Slichter (F '12) summarized as follows the financial statement included in the board report, covering the fiscal year ended April 30, 1946:

	1945–46	1944–45
Receipts for the year	*$537,476.29	$468,098.86
Out of pocket expenditures	395,978.86	374,373.19
Gain for year	141,497.43	93,725.67
Investments	125,084.27	66,600.49
Net cash gain	16,413.16	27,125.18
Assets		
Book value of all reserves	$483,572.94	$359,259.96
Accrued interest	89.75	89.75
Cash in reserve fund	47,304.66	35,677.79
Cash in working fund	81,379.47	77,206.09
Total assets	612,346.82	472,235.59
Investments		
Book value of all investments	$483,572.94	$359,259.96
Market value, May 1	552,893.92	398,266.61

* Includes gift of $10,652 from the estate of the late W. S. Barstow.

PRESIDENT-ELECT HOUSLEY INTRODUCED

J. Elmer Housley (F '43) AIEE president-elect for the administrative year August 1, 1946, to July 31, 1947, was introduced by President Wickenden, who pinned upon Mr. Housley's lapel the official gold emblem of the Institute president, stating that "it symbolizes the fact that during the year to come the Institute will have sound, energetic, genial leadership, and that you will find yourself welcome from the farthermost reaches of northern Canada to the southernmost points of Mexico."

Mr. Housley's message as incoming president appears on page 394 of this issue.

The election of E. W. Davis, O. E. Buckley, T. G. LeClair, R. F. Danner, and C. F. Terrell as vice-presidents; J. F. Fairman, R. T. Henry, E. P. Yerkes as directors; W. I. Slichter as treasurer; has been reported in detail (*EE, July '46, p 330*).

AIEE PRIZES AWARDED

As Chairman Morris D. Hooven (F '44) of the AIEE committee on award of Institute prizes read the citations and called the winners forward, President Wickenden gave the award and a personal word of greeting to James DeKiep (M '43), L. R. Hill, and G. L. Moses (M '44), for having prepared and presented the best paper in the field of engineering practice; to G. D. McCann (M '44), C. E. Warren (A '41), and H. E. Criner, for having prepared and presented the best paper in the field of theory and research; to Aram Boyajian (F '26) for having prepared and presented the best paper in the field of public relations and education; and to G. W. Scott, Jr. (M '45) for the best initial paper.

A detailed report of the prize awards, including a listing of those who won honorable mention in the different categories, has been published (*EE, July '46, p 351*).

WESTINGHOUSE CENTENNIAL

In special recognition of the 100th anniversary of the birth in 1846 of George Westinghouse, whose name long has been prominent in the electrical industry, a special address entitled "George Westinghouse, Individualist" was presented by J. K. B. Hare, vice-president of the Westinghouse Electric Corporation. Mr. Hare's address is scheduled for publication in a subsequent issue of *Electrical Engineering*.

LAMME MEDAL TO PRINCE

With appropriate ceremony, President Wickenden presented the AIEE Lamme Medal to D. C. Prince (F '26) past president AIEE and vice-president of the General Electric Company, "for his distinguished work in the development of high voltage switching equipment and electronic converters." (*EE, Mar '46, p 130*). A brief outline of the history and significance of the Lamme Medal was given by C. M. Laffoon (F '45) of the Pittsburgh Section, acting for Doctor John C. Parker (F '12) of the New York Section, chairman of the AIEE Lamme Medal committee. A biographical sketch reflecting the personal and professional attainment of the medalist was presented by H. E. Strang (M '39) of the Schenectady Section. In his response, Medalist D. C. Prince gave an illustrated talk reflecting a few of the human interest aspects of some of his technical developments.

The complete story of the Lamme Medal presentation, including the several addresses, is scheduled for publication in a subsequent issue of *Electrical Engineering*.

ENTERTAINMENT FEATURES

A program of entertainment activities, carefully planned and well executed by

the local committees, provided numerous inspection trips to points of technical interest, visits to points of artistic and historic interest, especially generous facilities for the annual golf tournaments, a twilight baseball game between the Detroit Tigers and the Boston Red Sox of the American League, a smoker for the men and a special dinner affair for the women, a wealth of separate affairs for the women including tea and a shopping tour across the border in Windsor, Ontario, topped off by the president's reception and a general dinner dance.

GOLF TOURNAMENTS

The Mershon trophy was won by Tomlinson Fort (M '35) of the Pittsburgh Section, one up over G. A. Kositzky (F '29) of the Cleveland Section; Fort and Kositzky having defeated K. M. Smith (M '33) and H. E. Wulfing (F '44) of the Chicago Section in the semifinals. The Mershon trophy was presented to the AIEE by Past President R. D. Mershon (F '12) and is available for competition by Institute members on the basis of match play and handicap. The trophy remains in the permanent possession of the Institute, on display in the member's reception room at AIEE headquarters in New York. Each winner is entitled to have his name engraved upon the trophy, and receives also a suitable memento of the occasion. The present trophy is the third such trophy donated by Doctor Mershon, the first two having been susceptible of being won permanently. The names appearing on the Mershon trophy now will be as follows:

1946 Tomlinson Fort (Pittsburgh Section)
1942 H. G. Schultz (Chicago Section)
1941 D. S. MacCorkle (New York Section)
1940 H. A. McCrea (Boston Section)
1939 F. R. George (San Francisco Section)
1938 T. G. Rudd (New York Section)
1937 C. H. Teskey (Cleveland Section)
1936 Carl E. Johnson (Los Angeles Section)

The Lee trophy was won by K. M. Smith of the Chicago Section, with H. E. Wulfing of the Chicago Section as runner-up. The Lee trophy was presented to the Institute in 1932 by the late Past President W. S. Lee, for competition among Institute members on the basis of lowest net score for 36 holes. The Lee trophy must be won twice by the same player for permanent possession. In the meantime, the trophy is on display at AIEE headquarters in New York, and the list of names of winners engraved upon it now will read:

1946 K. M. Smith (Chicago Section)
1941 T. H. Hogg (Toronto Section)
1940 H. E. Wulfing (Chicago Section)
1939 W. G. B. Euler (San Francisco Section)
1938 T. A. O'Halloran (Washington Section)
1937 G. A. Kositzky (Cleveland Section)
1936 H. S. Warren (Los Angeles Section)
1935 A. H. Sweetnam (Boston Section)
1934 F. M. Craft (Georgia Section)
1933 G. R. Canning (Cleveland Section)
1932 C. H. Teskey (Cleveland Section)

The exceedingly small number of registrants for the golf tournaments precluded the usual District team competitions, and otherwise generally disappointed the local committee which had made extensive and generous arrangements in anticipation of a lengthy registration of golfing enthusiasts. The tournaments were played at the Glen Oaks Golf and Country Club.

Electrical Contracting photo

W. E. Wickenden (F '39) outgoing president of AIEE (left) greets President-Elect J. E. Housley (F '43) at the summer convention

COMMITTEES

Essential to any successful convention is the hard work done over a long advance period by the volunteer group comprising the various local convention committees. The pronounced success of the summer convention in Detroit is creditable to the following committees:

General Committee

S. M. Dean, *chairman;* T. G. Glenn, *vice-chairman;* W. F. Wetmore, *secretary-treasurer;* A. H. Lovell, *District representative;* L. W. Clark, *Michigan Section chairman;* G. M. Chute, Jr., *Michigan Section secretary-treasurer.*

Hospitality Committee

M. A. Bergdahl, *chairman;* E. R. Moore, *vice-chairman;* E. B. Anderson; F. Bauer; A. B. Buchanan; G. M. Chute, Jr.; L. W. Clark; M. R. Horne.

Meetings and Papers Committee

A. E. Kriegsmann, *chairman;* A. W. Rauth, *vice-chairman;* J. S. Ambrose; J. S. Francis; C. H. Heiney; J. G. Hemstreet; H. L. Lindstrom; D. B. Masters; A. R. Satullo; W. C. Smith; J. W. Trachi; C. E. Waits.

Sports Committee

D. D. Chase, *chairman;* W. E. Leaie, *vice-chairman;* A. S. Albright; L. E. Donelson.

Hotels Committee

H. W. Collins, *chairman;* H. J. Morton, *vice-chairman;* O. J. Marshick; R. Pogorzelski; L. B. Potter; V. E. Schafer; P. A. Trachi.

Publicity Committee

A. J. Koetsier, *chairman;* A. P. Fugill, *vice-chairman;* E. L. Hubbard; R. E. Kratzer; R. H. Merta; H. Paransky.

Inspection Trips Committee

R. C. Spaulding, *chairman;* J. G. Spaulding, Jr., *vice-chairman;* E. L. Bailey; W. J. Campbell; E. L. Hubbard; K. W. John; H. F. Wall.

Information and Transportation Committee

W. J. Piper, *chairman;* A. R. Hellwarth, *vice-chairman;* A. E. Bush; C. E. Fishback; E. D. Kane; R. L. Rayner; E. Sakolov; D. E. Trefry; L. R. Wagner; H. F. Wall.

Finance Committee

V. J. Snyder, *chairman;* G. A. Strohmer, *vice-chairman;* G. M. Chute, Jr.; D. D. Douglass; R. Foulkrod; J. G. Hemstreet; H. M. Hess; W. F. Wetmore; W. R. Williams.

Registration Committee

F. R. Temple, *chairman;* W. G. Knickerbocker, *vice-chairman;* E. L. Bailey; D. H. Baker; G. M. Bunting; H. M. Craig; J. H. Schumann; H. P. Seelye; H. W. Sherwin; M. R. Steffins.

Ladies' Hospitality Committee

Mrs. M. A. Bergdahl, *chairman;* Mrs. S. M. Dean, *vice-chairman.*

Hospitality Subcommittee

Mrs. M. M. Cory, *chairman;* Mrs. H. Cole; Mrs. H. W. Collins; Mrs. S. M. Dean; Mrs. R. E. Greene; Mrs. V. J. Snyder; Mrs. H. F. Wall.

Yacht Club Luncheon Subcommittee

Mrs. F. R. Temple, *chairman;* Mrs. E. C. Balch; Mrs. G. M. Chute, Jr.; Mrs. J. H. Hunt; Mrs. T. N. Lacy; Mrs. W. J. Pefferly.

Dinner and Bingo Party Subcommittee

Mrs. D. D. Chase, *chairman;* Mrs. C. C. Adams; Mrs. T. R. Halman; Mrs. E. R. Moore; Mrs. W. F. Wetmore.

Greenfield Village Subcommittee

Mrs. L. W. Clark, *chairman;* Mrs. D. D. Douglass; Mrs. C. E. Fishbeck; Mrs. M. R. Horne; Mrs. L. B. Potter; Mrs. R. C. Spaulding.

Trip to Canada Subcommittee

Mrs. L. I. Komives, *chairman;* Mrs. A. S. Albright; Mrs. A. P. Fugill; Mrs. F. M. Hull.

Analysis of Registration at 1946 Summer Convention, Detroit, Mich.

Classification	Districts 1	2	3	4	5*	6	7	8	9	10	Elsewhere	Total
Members	131	232	60	40	360	11	25	14	10	37		920
Men guests	24	54	8	1	146	2	6	2		9	1	252
Women guests	22	30	9	11	74	5	11	5	2	1		170
Students	1				7					1		9
Totals	178	316	77	52	587	18	42	21	12	48	1	1,351

* District in which Detroit is situated.

Institute Activities Reviewed at Officers and Delegates Conference

Based upon the success and popularity of previous experiment, the Sections committee this year arranged a total of six separate conferences:

1. Main conference of officers, delegates, and members.

2. Conference on Section operation and management for the 19 larger Sections.

3. Conference on Section operation and management for the 29 Sections of intermediate size.

4. Conference on Section operation and management for the 28 smaller Sections.

5. Conference on Section activities in connection with local councils of engineering and technical societies.

6. Conference on Section–Branch co-operation.

Attendance at all sessions was very good, and included many officers and members other than the responsible delegates. Official delegates were present from all of the 10 Districts, and from 72 of the 75 Sections. The Sections not officially represented were Beaumont, Columbus, Fort Wayne, and Mansfield.

The following report is devoted to the general conference of officers, delegates, and members held Tuesday afternoon, June 25, 1946; the other conferences are reported separately, elsewhere in this or in a subsequent issue.

With Vice-Chairman R. M. Pfalzgraff (M '41) of the Philadelphia Section presiding, and A. C. Muir (M '39) of the Philadelphia Section acting as secretary, the conference program was arranged as follows:

1. Opening remarks by chairman.

2. Observations on Institute activities by Doctor W. E. Wickenden (F '39) AIEE president, of the Cleveland Section.

3. Opportunities for Section activities in the industrial field by President-Elect J. Elmer Housley (F '43) of the East Tennessee Section.

4. District and Section activities by Secretary H. H. Henline.

5. Sections committee report and forecast by G. W. Bower (M '40) of the Philadelphia Section, chairman of the Sections committee.

6. Progress report of committee on planning and coordination, pertaining to its study of Institute activities, by J. F. Fairman (F '35) of the New York Section, AIEE vice-president and chairman, committee on planning and co-ordination.

(a). Technical activities subcommittee, by M. D. Hooven (F '44) of the New York Section, chairman of the subcommittee.

(b). Professional activities subcommittee by T. G. LeClair (F '40) of the Chicago Section, chairman of the subcommittee.

7. Section membership activities and its relation to the progress of the Institute, by L. F. Howard (M '25) of the New York Section, chairman AIEE membership committee.

8. Institute finance and its relation to the Section, by W. R. Smith (F '30) of the New York Section, chairman AIEE finance committee.

9. Reports of the first year of operation of the two newest Institute Sections
(a). Beaumont Section.
(b). Illinois Valley Section.

10. Educational courses conducted by the Sections by H. W. Bibber (M '30) of the Schenectady Section, chairman AIEE committee on education.

11. AIEE publication services, by G. Ross Henninger (F '43) AIEE editor.

12. Section history by M. S. Coover (F '42) of the Iowa Section, AIEE vice-president.

13. General discussion.

PRESIDENT COMMENTS ON SECTION VISITS

President Wickenden reported that he had come back from his extended tours of visitations to AIEE Sections with "an indelible impression of the activity and the vitality of the Institute as expressed through its whole activity. . . . The Institute, through its local units, is setting the pace of professional activity over the country, setting it through widely diversified programs with an over-all scope for groups having specialized interests and aims and an attractive fare of general discussions and activities, and a social life that must gladden the hearts of the founders, who put equal weight upon the fraternal relations and the technical activities of the Institute, as these founders look over the rim of the other world and keep track of us.

"I was impressed, too," said Doctor Wickenden, "with the zeal with which the subsection activities over the country are pushing out our organized front. One cannot fail to be impressed by the great position of leadership which the Institute is exercising in the development of co-operative activities. . . . One finds in meeting representatives of the Institute of Radio Engineers that we are of one mind in regretting that there ever was a situation that tended to encourage a separation of interests between these two great bodies, and one finds an equal desire, apparently on both sides, that the evolution may be so guided that in the course of time . . . there may be a progressive coalescence of interests which might stimulate and result in the ultimate unity in the great field of electrical science and industry.

"Also, one is impressed by the unique value of the Institute in its solid trinational organization. In fact we are unique in being firmly established alike in Canada, in the United States, and in Mexico. It is of potentially great worth to us and to the nation that this bond of sympathy and understanding and collaboration . . . is being built up. . . . One is very happy to find that Canadian and Mexican members take great pride and satisfaction in their association with the Institute, and aspire to carry their full weight in its growth in numbers and in activity.

"I could not help being impressed by the significance of the great movement toward industrialization which is getting under way in Mexico City, and the unique opportunity which we of the Institute have not only to strengthen, but also to broaden, activities there, looking forward to the day when Mexico may stand with our Canadian neighbor on the north, as a fully developed geographical Section of the Institute with a vice-president representing it."

In paying tribute to the AIEE Sections committee for its indefatigable leadership and dynamic program, Doctor Wickenden reported to the conference that he came back from his field trips "with the impression that the energizing source for much of this vigor which the Institute shows is the Sections committee. I simply could not let this opportunity go by without expressing the admiration that your national officers have for the work which has been carried forward through that committee under the leadership of its chairman Mr. Bower. I do not believe that a finer job of organization has been done by any committee in any national engineering organization. These things are reflected in the membership gains of the Institute; they are reflected in the particularly strong financial position of the Institute; they are a challenge, I believe, to our national body to become as inclusive and as adaptive to new conditions, as enterprising in meeting and taking advantage of new situations, and as co-operative on the plan of our broader interests, as the local units of our organization have proved themselves so worthily to be."

PRESIDENT-ELECT EMPHASIZES IMPORTANCE OF INDUSTRIAL ELECTRICAL ENGINEER

President-Elect Housley laid especial stress on the need for expanding AIEE activities to serve more adequately the very large block of electrical engineers engaged in one or more of the many phases of industrial applications and industrial operations. He said: "I have been anxious to bring to your attention the problem of the industrial electrical engineer with which I have been struggling for some 30-odd years. The Institute has done a great deal for the industrial electrical engineer, but . . . we have a greatly expanded field of industrial activity, and we need to cover that field more adequately.

Mr. Housley called attention specifically to the importance of full AIEE participation in the work of Engineers Council for Professional Development. He spoke also of more active co-operation between the Sections and the AIEE committee on safety, with reference to the electroindustrial field. He challenged the membership committee with the statement that "The industrial field is wide open, and the surface has been scratched so far as membership possibilities are concerned . . . continued industrial expansion gives us an opportunity to share AIEE benefits with the engineers of industrial plants."

The essential substance of Mr. Housley's further comments are embraced in his "Message From the President" on page 394 of this issue.

SECRETARY HENLINE DESCRIBES SECTION AND DISTRICT DEVELOPMENT

Emphasizing that one of the most important benefits accruing from the steadily broadening fields of activity of the Institute's Sections and Districts is the increased

opportunity for active participation in Institute affairs by individual members, Secretary Henline stated that "Much of the progress of the Institute during the past 25 years has been the direct outgrowth of the soundness of the District and Section plans of organization, and the effectiveness of the activities carried on through the contribution of a very large number of individual members. This plan for organization of Districts came into being in 1920, after comprehensive studies by the AIEE committee on development, and was intended primarily to give members a closer contact with Institute officers, to develop interests among the younger members in particular, and to stimulate Section activities. I think that today, 25 years later, we can agree that the plan accomplished these objectives. . . .

"District activities, as carried on today, have evolved through numerous steps starting with the formation of the District executive committees as established in the by-laws, the subsequent provision for traveling expenses to a yearly meeting in each District, establishment of District prizes for technical papers, the appointment of District Student Branch counselors, the authorization of allowances for traveling expenses for District conferences on student activities, and other developments including the recent authorization for Sections to send three representatives instead of two to the District meetings. . . . Since the first District meeting was held in 1924, 50 such meetings have been held. They are intended to serve somewhat the same purpose as Section meetings, but on the larger physical scale of the geographical District, so that subjects of primary interest in the several Districts may be given appropriately specialized attention for the benefit of the members in those Districts.

"One of the most striking developments in Institute affairs has come within the past few years, in the remarkable expansion of Section activities. Some of the Institute's Sections have been in operation since 1902. Members in New York City held monthly meetings beginning in 1886; in Chicago beginning in 1894. The development of AIEE local Sections as an important part of the AIEE national program began in 1902 under the driving stimulus of the late Doctor Charles F. Scott who was president at that time.

"Reflecting on the growth of the Institute, we find the membership on May 1, 1902, to have been 1,549; on June 1, 1946, it was 25,218. We find in 1920, an Institute membership of 11,345 with 36 Sections holding 262 meetings that year; whereas during the fiscal year just closed, 75 Sections, 26 Subsections, and 82 technical groups held 1,187 meetings. The average number of Sections meetings for the fiscal year which ended April 30, 1920, was 7.3 meetings per Section; for the 1941–42 fiscal year 9 meetings per Section; for the 1945–46 fiscal year just closed April 30, 15.8 meetings per Section. A few years ago we thought a Section was carrying a normal load of activity if it held something like 8 or 9 meetings per year; now the average is nearly 16 meetings per year, in addition to educational courses and active participation in local joint engineering councils. At present Institute Sections participate in at least 45 local engineering councils; so far as is known, there is no local council located in an area covered by an Institute Section in which the Section is not active.

"The 125 Student Branches have had some difficulties in recent years, and nearly one third of them were inactive at some time during the war, but most of them already have resumed normal activities or expect to do so this coming fall.

"An index of the importance of student activities is given in the fact that during the past 15 years some 10,000 Associates have come into AIEE membership from the status of Student membership—some 40 per cent of all Associates elected during that period.

One of the most important functions of the Institute is to participate in the development of the individual—to help individuals in their own advancement—and this is being accomplished through the Branches at the start, later through the Sections activities, through the broadened District activities, and finally through participation in AIEE national affairs. All Institute activities are on a purely voluntary basis. No one is compelled to do anything. Therefore, results are attained by the adoption of activities that will stimulate and maintain maximum interest among a large number of qualified members.

"Special efforts are being made to provide greater flexibility in AIEE organizational structure, and greater diversity of opportunity for individual participation in a broadened program of AIEE activities, so that members almost anywhere may have the privilege of coming together and discussing problems of common and current interest. Recent developments in AIEE Sections activity have expanded such opportunities to an extent which now constitutes a challenge to the other division of AIEE activities, to attain equivalent effectiveness."

SECTION RECORDS REPORTED; NEW RECORDS FORECAST BY BOWER

The administrative year just closing has been a record year for AIEE Section activities, according to reports presented by G. W. Bower, chairman of AIEE Sections committee. He reported that "For several years prior to 1943, the number of Section and Branch meetings, together with totaled attendance at those meetings, had been decreasing progressively each year . . . reaching a low of 598 meetings with slightly over 66,000 total attendance in 1943." Progressive increases since that time led to the all-time record activity established for the fiscal year ended April 30, 1946, which showed a total of 1,187 meetings with an attendance total of something more than 116,000. These increases are of especial significance and importance, inasmuch as they occurred during the period of the war emergency.

"The organization and operation of technical groups and Subsections and the increase in other Section activities have been largely responsible for these results," stated Mr. Bower. "I look for a substantial increase in these figures during the forthcoming year . . . it should be the goal of every Section chairman to see to it that his Section contributes to this effort." Calling attention to the detailed report of the Sections committee included in the "Report of the Board of Directors" (*EE, July '46, pp 331–50*) Chairman Bower recounted some of the chief events of the year. A plan of increased national appropriation for additional Section activities; the formation of two new Sections—Beaumont (Texas) and Illinois Valley—during the year; transfer of the Mexico Section from the jurisdiction of the New York District (3) to the South West District (7); the transfer of the territory of Hawaii from New York District to the territory of the San Francisco Section in the Pacific District (8). "The pioneering spirit of the San Francisco Section was demonstrated by the efforts of its members to form a Subsection in the Hawaiian Islands," stated Mr. Bower, who reported further that:

"The development of technical groups is a very important part of the plan to retain the diversified interests of the older members, as well as to attract new members . . . the chairman of each Institute technical committee was contacted at the beginning of the year in an effort to enlist the co-operation of the individual members of these committees to encourage the development of new technical groups in their local Sections, as well as assist in the operation of such groups. The value of such groups operated within a Section is becoming recognized more generally throughout the country. The number in operation increased from 51 to 82 during the year; many others are in process of formation.

"Subsection operation is a valuable means of accomplishing the important objectives of the Institute, by providing additional meeting places at which papers on electrical engineering subjects may be presented and discussed. Many opportunities exist for members to participate in Section activities through the development of Subsections. . . . Subsection operation is becoming more popular each year as its advantages are recognized more widely." Eleven Subsections started during the past year have brought the total to 26; a total of 35 or more is expected to be in operation by the spring of 1947.

"Co-operation with other societies at the local level is being covered very satisfactorily by local councils of engineering and technical societies . . . in 45 metropolitan areas . . . which includes practically all the larger centers of population. This local council movement is spreading very fast, and I am sure that it soon will include all remaining metropolitan areas. The AIEE local Sections have been very active in many areas in the organization and operation of these local councils, and the Sections committee has encouraged this activity.

Mr. Bower reported that the Sections committee had worked very closely with the vice-presidents, keeping them completely

informed on Section committee plans. Specifically: "The vice-presidents held individual meetings on Section operation and management problems in connection with their District meetings in the fall of 1945. . . . These meetings were very successful. . . . This co-operation with the vice-presidents has been very profitable to the Institute and . . . should be encouraged and extended further." Mr. Bower reported further that the Sections committee had prepared and distributed a plan of Section–Branch co-operation, as a joint project with the committee on Student Branches; prepared and distributed a plan of suggested educational courses, as a joint project with the committee on education; is planning to encourage safety activity in the Sections as a joint project with the committee on safety. "Co-operation between Institute committees is very profitable for the Institute," said Mr. Bower, "it should be encouraged and extended throughout the Institute. More emphasis should be placed on this internal co-operation.

"Developments in the field of electrical engineering have expanded greatly during the period of the war emergency. Activities of the Institute also have expanded during this period, but the Institute must keep abreast in the diversification and expansion in the electrical engineering field in order to retain its leadership in this field as a Founder Society," urged Mr. Bower, "the Institute covers the entire broad field of electrical engineering, and it would lose much of its effectiveness if it were to surrender any of this broad field. Competition by specialized technical societies may become greater in the future, but if the Institute is fully alert to its responsibilities in the broad field of electrical engineering, this competition should be both stimulating and helpful."

PROGRESS REPORTED ON PLANNING AND CO-ORDINATION PROJECT

Studies currently being made by the AIEE committee on planning and co-ordination toward the objective of extending and improving the effectiveness of AIEE activities were outlined briefly by AIEE Vice-President J. F. Fairman, chairman of that committee. The phase of this study concerned with technical activities was enlarged upon briefly by M. D. Hooven, chairman of the subcommittee on technical activities and chairman of the AIEE technical program committee. The phase concerned with the so-called "professional" aspects was enlarged upon in some detail by Chairman T. G. LeClair of the subcommittee on professional activities. The subject matter embraced in these discussions has been included in reports variously published in *Electrical Engineering* during recent months, and given in some detail in the April issue (*pp 169–73*).

SECTION MEMBERSHIP ACTIVITY IN RELATION TO INSTITUTE PROGRESS

The importance of aggressive and constructive membership activity on the part of each Section, and the importance of selecting the right Section personnel for membership activity, were stressed by Chairman L. F. Howard of the AIEE membership committee. Statistics reported by Mr. Howard included the following: The Institute membership growth of 17.8 per cent, from 21,407, on April 30, 1944, to 25,218 as of June 1946, a two-year period; 500 applications currently pending; student membership at 5,087, as compared with a prewar high of 5,926 and a wartime low of 4,613; peak of 2,500 (in 1945) given "inactive status" because of military service, the total having dropped to less than 1,700 in June and steadily dropping as unsolicited requests for reinstatement are received daily; re-election or reinstatement of former members amounting to 401 for 1945–46, 366 for 1944–45, 301 for 1943–44; transfers from Associates and Member grades to higher grades of membership, 559 for 1945–46, 464 for 1944–45, and 420 for 1943–44; total losses in membership from all causes for 1945–46, 600, as compared with 702 for 1944–45.

"Such a growth is fascinating and stimulating," reported Mr. Howard, "can it be that this growth just happened? It would seem clear that world conditions generally and the industrial development outlook, as so clearly outlined by Mr. Housley, emphasize a need for persons to be alert to developments pertaining to all branches of electrical engineering. Granting that the AIEE naturally should be the organization favored to carry on effectively and to meet the challenge of the times, because of the unique position it has held in the field of electrical engineering development since 1884.

"There are other influences which have aided in membership work, particularly in the past few years. Much effort has been directed toward developing methods in membership work which would be suitable to the times and the conditions existing in the various Sections. . . . The 'Membership Committee Guide' has been made available to Section membership committees, and is available to all others interested . . . the recently issued booklet 'Membership Information' likewise should be helpful . . . the keeping of careful records by the Section secretaries and by the Section membership chairmen is important, and the passing of this information to successors has proved to be extremely helpful in maintaining continuity of effort.

The Sections committee during the same period has been more than usually active. . . . This in turn has aroused, broadened, and quickened the interest of the individual members, and additional qualified persons have become interested. . . . The membership committee can be instrumental in obtaining new members, but the membership committee cannot keep those members interested if other activities of the Institute do not give the members attractive programs and provide opportunities to keep the interest alive.

"It is the job of the membership committee, and it falls heavily on the Section membership personnel, to be ready at all times to assist in acquainting qualified persons with the advantages of becoming AIEE members. . . . Membership work is an important although not spectacular part of Institute activities. Membership work should . . . be a service from which real pleasure should result. Men who truly like people, and can approach them comfortably and sincerely, be responsive, and listen well, should welcome a call to serve on membership committees. Part of the membership gain which has been experienced in recent years must be credited to these factors. Personnel of the membership committee throughout the AIEE, with especial emphasis on Section membership personnel, has been particularly responsive.

It is through the Sections that new membership material is to be obtained, and present membership retained. We have the ability, the energy, the enthusiasm, and the courage to see that all the activities of the Sections are so correlated that we will be alive constantly to the technical, economic, and industrial developments, and thus assure that the influence and prestige of the AIEE will be even greater in the years to come than it has been in the past.

INSTITUTE FINANCE AND ITS RELATION TO SECTIONS

Increases in appropriations for Section activity expenses, and the correlative responsibility of Sections to make wise and productive expenditures of such appropriations, were outlined by Chairman W. R. Smith of the AIEE finance committee. He emphasized that the consistently sound financial condition of the Institute is the direct and accumulative result of the judgment, conservatism, and consistent efforts of finance committee personnel throughout the years. He emphasized also that essentially the only source of Institute income is membership dues, and that the constant problem of the finance committee is to weigh and evaluate suggested expenditures to assure continuing solvency on the one hand and achievement of the greatest over-all good for the Institute on the other hand.

Mr. Smith outlined current Section allotments, reporting the recently revised schedule of Section appropriations as follows:

1. Basic allowance per Section $200.
2. Additional allowance $1.20 per member.
3. Additional allotment: for 12 to 17 meetings, $50; for 18 to 23 meeting, $100; for 24 to 29 meetings, $150; and for 30 or more meetings, $200.
4. Additional allotment for each Subsection active $100.

Mr. Smith urged each Section to establish a budget and finance committee, to provide for specialized attention to this important phase of activity and to assure the most effective co-ordinated use of available funds, as well as to avoid overcommitment and overexpenditures.

NEW SECTIONS REPORT

In June 1945, two new AIEE Sections were organized formally, the Beaumont Section in Texas, and the Illinois Valley Section in the vicinity of Peoria.

Responding to a request for comments reflecting experiences of the initial year of operation, Chairman F. E. Dace of the Illinois Valley Section reported a 62 per cent growth in membership, from 47 at

the beginning of the year to 76 as of May 10, 1946. He reported further that during two years functioning of the group, including the year preceding their formal organization as a Section, 12 formally scheduled Section meetings and seven technical group meetings had been held in addition to two inspection trips, with a total attendance of 1,580 persons. The Section also is an active participant in the local engineering council, and is a member of the Illinois Engineering Council in recognition of the need for keeping in touch with affairs of an engineering nature throughout the state. The Beaumont Section was not represented at the conference.

SECTION EDUCATIONAL COURSES

A responsibility of the engineering school, in addition to giving its students a formal education in accordance with its curricula, is to impress upon those students that education is a continuing lifelong process, if they would keep up with the requirements of their profession; a combined responsibility and opportunity of the AIEE through its local Section is to assist the engineering graduate in his continuing education and professional experience, according to Professor H. W. Bibber, chairman AIEE committee on education. Professor Bibber pointed out that Sections currently have before them "two very specific opportunities; (1) of enabling the returning veterans who already have graduated from school to readjust themselves again to the technical side of engineering work; (2) to reconvert certain people who during the war were engaged in activities other than those in which opportunity now exists. In general we feel that the function of the Sections educational committee is to stimulate educational activity in the Section territory by whatever means may be most appropriate locally," he continued.

With respect to the establishment of educational courses by Section educational committees, Professor Bibber urged that full advantage be taken of facilities that might be arranged through established educational institutions within the Section territory, or of extension facilities of state universities or even other educational institutions more distantly located. He invited Sections to seek the advice of the AIEE committee on education concerning any problems within its province with which they might be confronted.

AIEE PUBLICATION SERVICES

A brief survey of current AIEE publication services was given by G. Ross Henninger, AIEE editor, based upon the following outline:

1. Advance pamphlet preprints of technical program papers.
2. *Electrical Engineering*.
   (a). General articles and news.
   (b). Transactions section.
3. "Transactions Supplement to Electrical Engineering."
   (a). June issue.
   (b). December issue.
4. AIEE annual *Transactions*.
5. Miscellaneous publications.

In comparison with this publication program which has been followed since 1938, Mr. Henninger briefly reviewed the history and evolution of AIEE publications from the original *Proceedings* as a meetings report, and *Transactions* as an annual repository of formally approved material. He also gave a brief preview of plans now being developed with the publication committee further to expand the scope of published material and to improve its distribution. Details of these plans will be enlarged upon in a later issue of *Electrical Engineering*.

SECTION HISTORY

The importance of maintaining a contemporary Section history was emphasized by Vice-President M. S. Coover, who urged that each AIEE Section establish and maintain a history committee. Mr. Coover suggested that the function of such a committee would be to build a history of local Section activity and of significant electrical developments in the territory of each Section. He urged immediate action of this project, in order that historical committees might have access to first hand information from many of the "old timers" who have grown up with the industry and are still available.

Four Papers Presented at Quality Control Conference

A conference on management and quality control was held June 28 during the summer convention in Detroit with W. P. Dobson (F '43) presiding. The following account of the conference was prepared by P. L. Alger (F '30) vice-president in charge of design engineering of the General Electric Company. In opening the meeting, the chairman reviewed the program of the Standards subcommittee on applications of statistical methods over the past year in organizing conferences and publishing a series of educational articles in *Electrical Engineering*.

W. S. Oliver, president of the Michigan Society for Quality Control, speaking on the topic, "Introducing Quality Control to Management," remarked that the newly formed national Society for Quality Control has over 2,000 members and some 21 regional organizations. Experience in war production has given a great impetus to the use of modern quality control methods throughout industry, but attention now is concentrated as much, or more, on human problems as on technical matters, according to Mr. Oliver. To introduce quality control into a plant, he recommended first the selection of some troublesome problem, such as a persistent defect, or absenteeism, or an unsatisfactory material, and then to devote a considerable period to collecting data on this one problem. After study involving preparation of charts showing daily variations, as related to different conditions, a report may be developed, showing the dollars saving that would result if the variations could be eliminated. By presenting this to management, support can be gained for a control program. Then, by careful selection of additional problems, maintenance of control charts on their variations, and preparation of a factual report on possible savings, the confidence of management can be gained. Ample time, probably six months, should be allowed for this building up of facts and confidence, before personnel is assigned to put quality control into effect throughout a plant.

The next speaker, James Rayer, superintendent of inspection, Timken Detroit Axle Company, stated that, when he first took a course in statistical quality control, he believed the methods were applicable only to large-scale production—an impression that has been generally shared by management. As presented, the course seemed academic—as though developed by men who knew nothing whatever of manufacturing. However, the evident ability of the instructors, and their conviction of the value of statistical methods, led him to continue to read and to think about them, with the end result that quality control now has been given the enthusiastic support of management in his company.

Mr. Rayer illustrated his remarks with a number of applications in the manufacture of axles, such as the study of variations in Brinell hardness and in the tightness and fits of wheel bearing adjusting nuts. Distribution charts of shaft hardness in one case showed a variation much wider than justified. Samples taken at various stages of the processing revealed the fact that some of the shafts were decarburized by overheating. Correcting the process at this point resulted in far more uniform production and important dollar savings. The same procedure of making distribution curves on samples of critical parts drawn from production, finding the spread to be wider than reasonable, tracing down and correcting the causes, and finally instituting control charts to maintain quality, is yielding very satisfactory gains in both quality and cost.

D. E. Durst, product control manager, United States Rubber Company, introduced his talk, "Plant Organization for Quality Control," by saying that times have changed since the days when "Bar X" meant a ranch in Wyoming—now manufacturing men recognize it as a symbol of "chart control"—the term that has been coined to describe the use of statistical methods for the control of quality. Mr. Durst said further that, in his opinion, quality control should be called "quality through people," since its success depends on inspiring operators as well as foremen to a creative interest in the quality of their work.

How to deal with people is an essential in training quality control engineers, Mr. Rayer declared. Twice as much time is spent on the human side as on the technical side of quality control in the course under his supervision. By making a control chart on each machine, and giving the operator the means for determining just how good his work is, a new interest is aroused, and a competitive or team spirit is developed, which produces benefits far outweighing the initial objectives.

In the absence of the author, G. S. Berge presented the paper, "Organization of Quality Control as a Management Tool," by T. D. Foy, supervisor of cost reduction, General Electric Company, Schenectady, N. Y. In Mr. Foy's opinion industry is more "tolerance conscious" than ever before; dimensions now often are required to be accurate to small fractions of a mil to meet customers' demands for higher quality products and interchangeable parts. In a large plant, where the operations of engineering, material ordering, planning and methods, manufacturing, and inspection and test all are organized separately, the problem of team work becomes all important. Quality control cannot be assigned to any one of these groups, but must be shared by all of them. Under this broader concept, quality control may be defined as "any organized management effort, statistical or otherwise, to establish and maintain required quality levels by suitable corrective and preventive action."

After consideration and trial of many different organization methods, Mr. Foy's experience indicated that the best plan in a large company is to make the quality control program the direct responsibility of management. In a typical division of his company, management is represented by an engineer responsible for the design and development of the product and a superintendent responsible for its production. The quality control program, therefore, is directed by a quality control coordinator reporting directly to the superintendent, and a quality control engineer reporting to the engineer in charge, these two men working in close co-operation. In this way all of the activities of developing, material ordering, planning, manufacturing, and inspecting can be organized to produce the most effective results. This program in no way relieves the foreman or the engineer from their immediate responsibilities for quality. Instead it provides them with facilities for applying distribution curves, control charts, and sampling tables to their problems.

Operation and Management Are Topics at Section Conferences

To afford time and opportunity for more thorough discussion of problems of common interest, and for the exchange of experiences among Sections of approximately similar size, the AIEE Sections committee arranged three separate and parallel conferences at the summer convention in Detroit, one for the larger Sections, one for the intermediate Sections, and one for the smaller Sections. These conferences were well attended, not only by the delegates of the Sections in the three groupings, but also by many Institute officers and other members.

COMMON PROGRAM

The conferences were conducted in an entirely informal manner, each session developing by discussions and questions from the floor. As a general theme for the guidance of major discussion, and to assure that certain important points were brought into the discussion, as well as to provide a pattern for future reference and use, the Sections committee arranged the following common program for the three conferences:

1. Operating committees.
2. Technical groups.
3. Fellowships.
4. Section prize paper competition.
5. Liability of Sections for injuries at meetings.
6. Subsections.
7. Other activities.

These sessions were held Monday afternoon, June 24, 1946, in conference rooms at the Detroit-Leland Hotel, a short distance from convention headquarters.

LARGER SECTIONS

With A. C. Muir (M '39) and H. H. Sheppard (A '34), both of the Philadelphia Section, presiding respectively as chairman and secretary, the conference of larger Sections included delegates from the following Sections:

Boston	Milwaukee
Chicago	New York
Cleveland	Philadelphia
Connecticut	Pittsburgh
East Tennessee	St. Louis
Los Angeles	San Francisco
Lynn	Schenectady
Maryland	Seattle
Michigan	Toronto
Washington	

High lights of this conference, as furnished by Secretary Sheppard, are reflected in the following. Experiences reported by the larger Sections indicate that an increase in the number of active operating committees is of value in furthering the administrative work and general activities of the Section comparable with the value of additional technical committees and groups in the furtherance of Section technical activities. One of the most active of such committees reported upon was a veterans committee to advise returning servicemen concerning their educational and employment problems through the medium of informal meetings which provide the benefit of direct council and conference with selected engineers representing the different branches of the profession. The 31 new technical groups activated during the year have brought the total to 82, with many more currently in process of formation and scheduled for activation with the opening of the fall season.

Typical of the experience of the larger Sections in the matter of Subsections, is that of the San Francisco Section with reference to Subsections, one at Sacramento about 90 miles away, and one at Fresno about 180 miles away. These two thriving and semiautonomous groups have been developed in areas in each of which it was reported that there were only two active AIEE members prior to the initiation of Subsection activity.

The following two resolutions were adopted unanimously:

1. Resolved that AIEE headquarters furnish to the secretary of each Section the names of references of newly elected members.

2. Resolved that the booklet on national and District prizes, now being revised, include a chapter giving recognition to Section prize paper competition, and making available financial assistance to those Sections having prize paper competitions.

The argument in favor of resolution number one, is that it would enable the Sections to encourage the attendance of newly elected members through contact with the supporting references. The argument in favor of resolution number two represented the strong feelings, long held by the more active Sections, that paper prize competition at the Section level is at least as important, if not more important, than such competition at the District and national level.

The delegates and members present at the conference were enthusiastic about the success of the meeting and recommended continuance of the idea at subsequent summer conventions.

INTERMEDIATE SECTIONS

With R. M. Pfalzgraff (M '41) and W. F. Henn (A '41), both of the Philadelphia Section, presiding respectively as chairman and secretary, the conference of intermediate Sections included delegates from the following Sections:

Akron	New Orleans
Central Indiana	Niagara Frontier
Cincinnati	North Carolina
Dayton	North Texas
Denver	Oklahoma City
Florida	Pittsfield
Fort Wayne	Portland
Georgia	Providence
Houston	Rochester
Kansas City	San Diego
Lehigh Valley	Sharon
Mexico	Spokane
Minnesota	Springfield
Montreal	Vancouver
Virginia	

The delegates from the intermediate Sections also adopted the resolution calling for some provision for Section prize paper competitions in the rules of the committee on award of Institute prizes. Chairman Pfalzgraff further urged that each Section form a prize paper committee. This activity was discussed by C. W. Lytle (M '42) of the Kansas City Section, A. D. Forbes (M '42) of the Sharon Section, and D. D. MacCarthy (A '28) of the Pittsfield Section.

A promise of increasing numbers of technical groups and Subsections in the coming year could be gathered from the attitudes of those taking part in the discussion. Experiences with technical groups were related by C. W. Lytle, W. M. Allen (M '44) of the Portland Section, J. D. Hershey (A '40) of the Niagara Frontier Section, and A. J. Hendry (A '39) of the Minnesota

Future AIEE Meetings

Great Lakes District Meeting
Indianapolis, Ind., October 9–11, 1946

Winter Meeting
New York, N. Y., January 27–31, 1947

North Eastern District Meeting
Worcester, Mass., April 23–25, 1947

Section. Subsections were discussed by Dean E. H. Flath (F '43) of the North Texas Section, J. D. Hershey, and A. J. Hendry. The subject of Section operating committees was discussed by W. A. Dynes (M '43) of the Dayton Section, A. J. Hendry, W. M. Allen, and R. S. Kersh (M '45) of the Houston Section.

Other Sections activities recommended as desirable were weekly luncheons, which were proposed by K. E. Stroppel of the Cincinnati Section, L. A. Goalby (A '40) of the Denver Section, and G. F. Price (M '44) of the Georgia Section; and a monthly Section news letter, which was described as especially advantageous for Sections with a scattered membership in extensive territory by L. A. Goalby.

SMALLER SECTIONS

With G. W. Bower (M '40) of the Philadelphia Section and C. S. Purnell (M '35) of the New York Section, presiding respectively as chairman and secretary, the conference of smaller Sections included delegates from the following Sections:

Alabama	Muscle Shoals
Arizona	Nebraska
Beaumont	New Mexico–West Texas
Columbus	South Bend
Erie	South Carolina
Illinois Valley	South Texas
Iowa	Springfield
Ithaca	Toledo
Louisville	Tulsa
Madison	Urbana
Mansfield	Utah
Memphis	West Virginia
Montana	Wichita

Worcester

The smaller Sections joined with the two other groups in adopting the resolution on Section prize paper competitions. The subject of prize paper competitions was discussed by W. E. Boruh (A '42) of the Toledo Section and R. D. Finnell (A '38) of the Wichita Section.

In the discussion on technical groups which was led by N. L. Platt (A '43) of the Ithaca Section, C. D. Higleyman (A '41) of the South Bend Section, E. W. Stone (M '37) of the Illinois Valley Section, and L. F. Rylander (M '37) of the Tulsa Section, it was concluded that audience participation in discussion was a better measure of the success of a technical group than mere attendance figures.

The connection between increased Section activities and increased membership and attendance at meetings was strikingly indicated by the experiences of the Alabama Section described by C. F. Sittloh (A '39).

Electronics Courses Are Subject of Conference

"Electronics in the Electrical Engineering Curricula" was the subject of a special conference held during the Detroit summer convention, sponsored jointly by the AIEE committees on electronics and education. The conference was held Monday, June 24, at the Hotel Statler. Professor H. W. Bibber (M '30) chairman of the AIEE committee on education, acted as chairman of the conference, and prepared the following notes covering its high lights.

In opening the conference, the chairman recalled the situation of 15 years ago when a few colleges had just begun giving electronics courses. Text material was inadequate, laboratory experiments were primitive, and the courses were definitely separate parts of the curricula. Today these early difficulties with the teaching of electron-tube characteristics and their use in rectifiers, amplifiers, oscillators, and modulators have disappeared. At present the unsolved question is what to teach through lectures and laboratory regarding microwave phenomena and the performance of wave guides.

Chairman Bibber observed that the presentation of ultrahigh frequency techniques to students had been well developed in a few institutions since 1942, but that the committees sponsoring the conference felt that an exhibit of up-to-date small-scale equipment, such as most colleges could use, would be appreciated by many teachers who were present at the convention. He admitted communications into the broad interpretation of the word "electronics" in the title of the conference.

Both elementary and advanced levels were treated in the two demonstration lectures:

"The Qualitative Demonstration of Microwave Phenomena Using Simple Equipment," by W. C. White (M '30) of the Schenectady Research Laboratory of the General Electric Company.

"Wave Guide Equipment With Interchangeable Terminations and Means for Quantitative Measurements," by Professor F. W. Smith (M '44) of Lafayette College.

Mr. White's demonstration had several humorous twists. For example, he showed the interception by his body of a microwave beam that apparently was coming out of a wall of the room. The mystery was cleared up when it developed that there was a small microwave transmitter concealed in a closet. The transmitter projected a strong beam through a six-inch brick wall. Another experiment showed the magazine, *New Yorker*, to be transparent to microwaves, while *Electrical Engineering* blocked them almost completely, though there seemed little difference in thickness. It then was revealed that a sheet of tinfoil between the pages of the latter might have had as much to do with blocking the wave beam as the heavier reading matter contained therein. Mr. White performed with microwaves almost all the experiments which can be done with visible radiation.

In a relatively few minutes Professor Smith showed an extensive series of experi-

Electrical Contracting photo

Recipients of the 1945 AIEE prize paper awards are shown after presentation of the awards at the summer convention in Detroit. Left to right in the back row are: James De Kiep (M '43) of the Westinghouse Electric Corporation; G. W. Scott, Jr. (M '45) of the Armstrong Cork Company; and C. E. Warren (A '41) of the Westinghouse Electric Corporation. In the front row are: G. L. Moses (M '44) of the Westinghouse Electric Corporation; Aram Boyajian (F '26) of the General Electric Company; G. D. McCann (M '44) of the Westinghouse Electric Corporation; and L. R. Hill of the Westinghouse Electric Corporation

ments on wave guides, made possible by the means he had devised for the rapid and convenient interchange of parts of his equipment. The readings of a meter were projected on a screen, so that quantitative measurements were indicated. Both rectangular and circular guides were demonstrated, with sketches of the modes of propagation being shown on charts. Several different terminations for the guide were used, and the effect on "standing-wave ratio" was indicated clearly by meter readings. The electric field probe and the loop probe for magnetic fields both were employed to show the nature of the field pattern present in the guides.

In the discussion period following the demonstrations, the desirability of regarding the equipment which had been shown as a regular part of each school's apparatus, and not as something novel or special was emphasized. Microwave phenomena should be regarded as an extension of the study of radiation in physics, and the wave guide as the latest addition to power transmission theory, it was suggested. If students were taught that power at low frequencies really was transmitted through the *space* surrounding the wires or an ordinary overhead line, rather than *in the wires*, the flow of power through the space inside a wave guide would not be so difficult for them to grasp. This thought led to an appeal for the teaching of a greater amount of field theory to all electrical engineers.

How time can be secured for the presentation of recent developments in electronics and communication was a question of concern to many of the audience. The congestion in present electrical engineering curricula is such that new material cannot be added without something being dropped. With the setting aside of 20 per cent of the available hours of the curriculum for humanistic–social studies, and the need for every engineer to study mechanics and thermodynamics, it seemed that greater efficiency in presenting course subject matter was the first answer, with graduate study for the technically gifted student becoming more common, a second answer.

A study of the newer developments in the microwave field for all staff members of departments of electrical engineering throughout the country was suggested as desirable, so that the ideas involved might infiltrate to the students through as many different courses as possible. There seemed to be a definite sentiment against localizing the instruction in microwaves and wave guides in a course entitled "Ultrahigh Frequency Techniques," as was done in many wartime curricula. Nor was there advocacy of a communications curriculum starting in the freshman or sophomore year. Rather, there was a distinct emphasis on the unity which, it was urged, can and should exist in all electrical engineering curricula, where a definite effort to teach fundamentals basic to all later specialties is made, and little attention is paid to the short-sighted demands of many students these days for a narrow specialization in electronics and radio.

The meeting closed on a note stressing the curriculum as a means of preparing the student for life, along with the extra-curricular activities of a school. Electronics should be an integral part of the physics and usual electrical engineering courses rather than be separated out entirely into discrete course work. The order of importance of the aims of any curriculum, it was asserted, should be: first, the development of the student as an *individual* and a citizen; second, his preparation as an *engineer* broadly conceived; and third, his specialization as an *electrical* engineer.

Local Councils Reported As Important Section Activity

With local councils of engineering and technical societies now active in some 45 metropolitan areas throughout the United States, this local joint activity rapidly is assuming an ever more important place in AIEE Section affairs, as it provides an effective medium, or meeting ground, for joint consideration and action on problems of common interest by the diverse elements of the technical and professional engineering field. In recognition of the increasing importance of this activity, the AIEE Sections committee arranged for a separate conference at the Detroit summer convention to provide an opportunity for the discussion of Section activities in relation to such joint enterprise. This conference was heavily attended, not only by Section delegates, but also by officers and other interested members of the Institute.

The conference provided opportunity for a review of the organization and operation of local councils, with particular emphasis on the active part that AIEE Sections have taken in this work. The three general types of local council organizations were described and discussed. Not only was this interchange of information valuable to those Sections already participating, but also it is expected to be especially useful to Sections needing assistance in expanding the activities of existing councils or in forming councils where they do not exist.

This conference was held Wednesday afternoon, June 26, 1946, at the Hotel Statler in Detroit, as a part of the summer convention program of the AIEE Sections committee. G. W. Bower (M '40) chairman of the AIEE Sections committee, presided, and A. C. Muir (M '39) served as secretary.

In opening the meeting Chairman Bower noted the widespread interest in local councils, there now being 45 such councils in active operation. He declared that "in most cases not only the AIEE Sections but also individual AIEE members have been very active in the work of these councils. This activity has been encouraged by the Sections committee. The continued growth of the councils and the expansion of their activities is factual proof that they are filling a need for co-operative efforts of all engineers in civic, legislative, and other similar broad activities of the engineering profession. The organization of these local councils has not followed a single pattern, and it is not really essential that they should."

E. B. Hansen (M '36) chairman of the Seattle Section presented a comprehensive report, written by R. E. Kistler (M '30), president of the Puget Sound Council of Engineering and Technical Societies, covering the organization and operation of local councils.

A. L. Duna (M '42) chairman of the Worcester Section, briefly described the operation of the Worcester Engineering Society.

F. R. Temple (M '21) Michigan Section representative on the Affiliated Council of the Engineering Society of Detroit, reported on that council.

J. C. Strasbourger (M '40) chairman of the Cleveland Section, outlined the organization and operation of the Cleveland Technical Societies Council.

T. M. Linville (M '34) member of the Sections committee, described the Schenectady Engineering Council; and L. R. Janes (M '29) chairman of the Chicago Section, described the three councils which are in operation in the Chicago area.

E. W. Morris (M '35) chairman of the Los Angeles Section, reported on the work of the Los Angeles Engineering Council.

C. M. Lytle (M '42) chairman of the Kansas City Section, outlined the organization and operation of the technical societies council of the Kansas City area.

R. E. Stroppel (A '34) chairman of the Cincinnati Section, described the operation of the Cincinnati Engineering Societies.

P. L. Alger (F '30) AIEE director, pointed out that local councils can increase their usefulness by engaging in civic projects within their metropolitan areas.

E. S. Lee (F '30) chairman of the Engineers Council for Professional Development, reported on the work of ECPD, stating that local councils can be of enormous help in furthering its progress, as outlined in the bulletin, "Will You Help?"

S. C. Leibing (M '36) chairman of the Central Indiana Section, enumerated the elements of successful council operation as a guide for councils in the future, using the organization of the Indianapolis Technical Societies Council as a background.

F. E. Sanford (M '34) until recently a very active leader in the local council activities of the Cincinnati Section, speaking for the local council of the future, stressed the point that the primary purpose of a local council is to be of service to the members of the member organizations, and that the first job of such a council is to issue a local weekly announcement to tell all members what all societies are doing. He predicted that some national organization would evolve, and that the local councils are the first step in this evolution.

The discussion at the meeting indicated that local councils are developing rapidly and have been very successful wherever they have been started. They seem to be the first step toward unification of the engineering profession, and have increased immeasurably the co-operation between local sections of the engineering technical societies. It is significant that in all cases re-

ported the local AIEE Sections and members have been active in the formation of and the work of the local councils. In many cases the AIEE was the dominant factor.

Student Activities Discussed at Conference

A conference on student activities, under the chairmanship of E. W. O'Brien (M '37) of the Atlanta Section chairman AIEE committee on Student Branches, was held Thursday morning, June 27, 1946, as a part of the summer convention program in Detroit, Mich. The following highlights of this conference were reported for *Electrical Engineering* by E. M. Strong (M '40) of the Ithaca Section.

The agenda for the conference covered the following points:

1. Report of subcommittee on joint Student Branches.
2. District conferences on student activities.
3. Prizes.
4. Branch activities of interest to veterans.
5. Expiration of student membership at age under 21.

Three major projects of especial concern to the committee on Student Branches during the past year were indicated by the chairman:

1. The re-establishment of student conferences, separately, or in conjunction with District meetings where possible.
2. Revision of the booklet, "The Electrical Engineer."
3. The development of Joint Student Branches.

JOINT STUDENT BRANCHES

Chairman O'Brien reviewed his action of last fall leading to a tentative approval in principle by the board of directors at the 1946 winter convention of a proposal providing for reciprocal recognition of student membership in the several recognized engineering societies. Mr. O'Brien then called upon Professor J. F. Calvert (F '45) of Northwestern University for report of a subcommittee appointed to expedite cooperation among the Student Branches of the several engineering societies in their local activity. Professor Calvert reported a recommendation which embraced two items:

1. A proposal for specific change in the wording of Section 64 of the AIEE bylaws, to authorize and implement the proposed joint Student Branches.
2. Additional procedure to expedite the proposed program of joint Student Branches beginning in the fall of 1946.

In the prolonged ensuing discussion, Chairman G. W. Bower (M '40) of the AIEE Sections committee seriously questioned the ultimate effect of the joint Student Branch proposal on AIEE activity, identity, and membership. The conference group took action, however, endorsing the proposal and transmitting it to the board of directors, then in session, for consideration and action.

Discussion clarified one important point: That the proposed program of joint Student Branches is not in any way mandatory, but is intended to be permissive only to enable such joint activities to be undertaken entirely on the basis of local option.

GENERAL DISCUSSION

There was brief discussion, but no action, on the subject of prizes.

Chairman J. H. Pilkington (M '34) of the New York Section described that Section's very active program of special counseling service for returning veterans. The report stimulated considerable interest, and brought suggestions that the New York Section prepare a descriptive report covering its project for publication (page 410 of this issue).

Favorable action was taken by the conference in support of a proposal to recommend to the board of directors that continuance of Student membership status be extended to graduates, effective until those graduates become 21 years of age.

Welding Conference Presents Popular Papers

Approximately 50 people filled the Ivory Room of the Hotel Statler in Detroit for the conference on arc welding held at 2 p.m., June 26. Among the audience were a number of designing engineers representing the electric welding industry and representatives of a half dozen power companies, as well as representatives from the Rural Electrification Administration, the American Welding Society, and the United States Bureau of Ships.

Exceptional interest was displayed in the papers, "Influence of Magnetic Materials on the Welding Characteristics of Resistance Welding Machines" and "Voltage Change Due to Resistance Welding Loads." The first-mentioned paper described how for the first time the effect of the introduction of magnetic materials into the throat of a resistance welding machine could be predetermined within limits. The effect of the introduction of such materials with reference to power factor also was given. Discussion was halted only by adjournment of the conference.

Because of the evident interest among those present in the question of power supply, it was decided to hold a conference on that subject at the 1947 winter convention. C. I. MacGuffie (M '43) presided. Mr. MacGuffie and G. W. Garman (M '43) chairman of the electric welding committee, prepared the foregoing notes for *Electrical Engineering*.

Section–Branch Co-operation Considered at Joint Conference

Ways and means of developing more effective co-operation between AIEE Sections and Student Branches were discussed extensively at a summer convention conference held Thursday, June 27, and sponsored jointly by the AIEE committees on Student Branches and Sections. This conference was presided over by Professor V. P. Hessler (F '43) of the University of Kansas (Kansas City Section) who prepared the following notes for *Electrical Engineering*. The program for the conference, as followed by Professor Hessler was:

1. Basic opportunities of Section–Branch co-operation, by Chairman E. W. O'Brien (M '37) of the AIEE committee on Student Branches.
2. The plan of Section–Branch co-operation, by Chairman G. W. Bower (M '40) of the AIEE Sections committee.
3. Typical examples of profitable Section–Branch co-operation.
5. A look into the future as a result of Section–Branch co-operation, by Past Vice-President Everett S. Lee (F '30) of the Schenectady Section, chairman, Engineers Council for Professional Development.

The conference group included Section delegates, chairmen of District committees on student activities, Student Branch counselors, and others.

In his opening address, Chairman Hessler pointed out that, since the schools are returning to more normal operation, now is the right time to consider Section–Branch co-operation.

E. W. O'Brien recommended a well thought out plan for Sections and Student Branches to provide help to the young engineers just graduated from college. This would benefit not only the students, but also the older members participating in it.

G. W. Bower outlined the 14 methods which make up the plan for co-operation between AIEE Sections and Student Branches, which is a joint activity of the Sections committee and the committee on Student Branches. Mr. Bower pointed out that many Sections now are following one or more of these methods, but no Section is using all of them. The percentage of new AIEE members coming from Student membership is now 40 to 50 per cent and should be increased, according to Mr. Bower, who disclosed that 49 Sections did not report having a student activities committee at the end of last year.

C. M. Lytle (M '42) chairman of the Kansas City Section, reported that the Kansas City Section followed a number of the items in the plan of co-operation and that the Section held meetings at the Student Branches. The Section also has been active in vocational guidance.

J. R. Jarvis (A '40) chairman of the Utah Section, reported active co-operation with Student Branches. The Student Branches frequently provide the program for the annual dinner dance of the Section. Once each year the Section has a joint meeting with the Student Branches.

C. K. Haspel (M '31) chairman of the Vancouver Section, outlined the Vancouver Section's methods of co-operation with the Student Branches.

E. W. Schilling (F '44) chairman, District committee on student activities, District 9, reported that the Student Branch at Bozeman, Mont., comes to the Section meetings at Butte, Mont.

J. H. Pilkington (M '34) chairman of the New York Section, stated that 50 of the Section's members act as counselors at the conferences held by the Section's veteran

committee. The committee has held 28 weekly conferences since December, and has counseled 750 veterans (page 410 of this issue).

H. W. Bibber (M '30) chairman of the committee on education, recommended that every effort should be made to get the students in touch with the world right at the start of their engineering education instead of waiting until commencement.

G. Strosberg, Student Member, advised that the American Society of Mechanical Engineers had issued an invitation to all of the student members of ASME at the universities to help out at the ASME convention in Detroit early in June. The Student Members of AIEE were disappointed that they did not receive a similar invitation from AIEE to help out at its convention.

Doctor Abe Tilles (M '46) chairman of the San Francisco Section, outlined the methods used by the San Francisco Section for co-operation with the Student Branches. He pointed out that not only should there be a real desire on the part of the Section and the Branches to co-operate, but that they should plan and execute a program to this end.

W. C. Osterbrock (M '41) of the Cincinnati Section reported that the Cincinnati Section has a subcommittee on student activities. Selected senior students present theses at the joint meeting with the Branches, which often includes members from other societies.

E. S. Lee predicted a glowing future for Section–Branch co-operation, which included: 100 per cent of Student Members coming into AIEE; an understanding of the profession by the student; and, an impress of the engineer on the school.

Technical Sessions Sponsored by Committee on Safety

A well-attended technical session sponsored by the AIEE committee on safety was held June 24 at 2 p.m. in the English Room of the Hotel Statler, Detroit. Through the presentation of three papers, the committee directed attention to aspects of accident prevention of concern to the electrical engineer. L. F. Adams (F '42) presided and W. R. Smith (F '30) supplied the following notes on the session.

Progress in the development of electric equipment and of commercial devices using electric energy has shown the necessity for a more extensive knowledge of the effects of electric shock, particularly with regard to maximum currents that human beings may be expected to withstand without serious consequences. Professor C. F. Dalziel (M '39) of the University of California, in his paper, "Dangerous Electric Currents," extended his previous work on "let-go currents" to discuss lethal currents and their accompanying physiological effects. His paper interprets the data of an earlier AIEE paper and suggests threshold current values likely to produce instantaneous electrocution in 1/2 per cent of a large group of normal men.

A conference paper prepared by R. L. Lloyd (A '37) of the National Bureau of Standards and M. M. Brandon (F '44) Underwriters Laboratories, Inc., and presented by the latter, dealt with the fundamental aspects of shock hazards of low voltage and emphasized the importance of education to promote a better understanding of the correct use of ordinary commercial and household appliances, especially those of the portable type. Whereas the number of electrical fatalities from low voltage which occur each year is so small as to be statistically insignificant in relation to other causes of death in homes and industrial establishments, even these few cases cannot be ignored, and their further reduction depends upon proper use of approved equipment on circuits complying with the requirements of the National Electrical Code.

The wide increase in the past several years of the use of X rays and gamma rays from radioactive materials for the purpose of nondestructive inspection of industrial products has made important a proper understanding on the part of users of the fact that radiations may injure seriously workers who are inadequately protected. In a paper entitled "Silent Invisible Industrial Hazard," S. Reid Warren, Jr., associate professor of electrical engineering at the Moore School of Electrical Engineering, University of Pennsylvania, described the properties of these rays, outlined the fundamental principles underlying protection of workers, and suggested practical methods of protection which have been devised and tested in industry.

Recorders Described At Conference on Instruments

A conference on electronic instruments held at 2 p.m., June 24, in the Bagley Room of the Hotel Statler with W. R. Clark (M '44) presiding drew an attendance of approximately 150 persons. Six papers were presented dealing with electronic recorders for potentiometric and bridge-type instruments. In his opening remarks Mr. Clark briefly recounted the history of electronic recorder development.

Papers by A. J. Hornfeck (M '43) of the Bailey Meter Company and V. L. Parsegian of C. J. Tagliabue Company brought forth a number of discussions. Mr. Hornfeck discussed in detail the operation of the 2-phase motor-driven slide-wire in the Bailey electronic recorder, for which one phase is supplied by the line. The other is supplied by the output of an amplifier which amplifies the unbalanced voltage of the potentiometer or bridge sufficiently to drive the slide-wire to a balanced position. For d-c potentiometer measurements, a converter is used. In the system described by Mr. Parsegian, a mirror galvanometer detected the unbalance of the potentiometer. Light reflected from the mirror was picked up by photoelectric cells which controlled the direction of rotation of the slide-wire circuit. Special circuits were used to obtain proper damping even at high speed operation.

A more detailed consideration of "D-C to A-C Conversion Systems" was given by W. P. Wills (M '42) of the Brown Instrument Company. Mr. Wills' treatment of the subject covered reasons for converting d-c unbalance of the potentiometer circuit to alternating current, the methods used, the history of this development, and the problems encountered, the life span of the converters, the contact potential problem, and the a-c pickup.

"The Input Transformer Problem" was presented by A. J. Williams, Jr. (M '45) of the Leeds and Northrup Company. It dealt with the problem of shielding transformers, so that they can be used at the lower power levels required for input transformers for electronic recorder amplifiers. Electrostatic and magnetic shielding methods were explained, and improvements in the construction and materials for the shields were described.

A recorder which employs a capacitor operated by a solenoid to balance an a-c bridge was described in a paper, "Process Variables Made Available by Electronic Methods for Industrial Measurements," written by D. H. Fuller of the Foxboro Company. High speed operation without overshooting is obtained with this instrument. For temperature measurements, the limiting factor is the speed of response of the resistance thermometer. A working model of the recorder was demonstrated after the meeting adjourned.

Sweep balance recorders in which the slide-wire is not driven to a balance position were introduced by George Keinath (M '37) and R. K. Hellman (M '45) of the Great American Industries, Inc. A stylus is continuously and smoothly moved across the chart. The slide-wire contact of the potentiometer or bridge circuit also moves with the stylus, and, when the contact passes over the balance position of the slide-wire, a spark discharge occurs from the stylus to the chart driving-roll, thus making a record of the balance position. Multiple point recorders also were described in detail.

Technical Committees Meet at Convention

Chairmen of the various technical committee meetings and conferences held during the recent summer convention in Detroit were invited to submit for news publication in *Electrical Engineering* memoranda covering any points of their meetings considered to be of some general interest and value to the AIEE membership. Out of that group, the following were received.

CARBON BRUSHES

The following résumé of the June 27 meeting of the subcommittee on carbon brushes was reported by Professor V. P. Hessler (F '43) of the Kansas City Section.

The meeting started at 9:30 a.m. with all but four of the members present and with several additional interested members in attendance. Ed Kaplan represented the carbon section of National Electrical Manu-

facturers Association and served as well as a member of the AIEE committee.

An outline of the major items which eventually should appear in the brush test code first was discussed. These items then were divided into two groups, first those in which technical progress warranted writing of a preliminary code and, second, those upon which further research and development was required before the code statement could be commenced. The items of the first group were assigned to various members of the committee for writing. This material will be assembled by the chairman and presented to the group at a meeting in January. The items of the second group also were assigned to various members, but it is not expected that this work will progress so rapidly.

It is the intention of the committee to prepare a preliminary code of those items upon which the industry can agree at present and then to add additional much-needed items as rapidly as possible.

The carbon brush committee also hopes to join with the d-c machine committee in a session at the January meeting.

METALLIC RECTIFIERS

The metallic rectifier subcommittee held an all-day session Tuesday, June 25, and met again on Wednesday afternoon. On Thursday morning it joined the power converter group to discuss common problems. The committee approved a list of standard definitions and a test code, copies of which now will be distributed in due course with the object of obtaining maximum comments from the general membership. These projects eventually will be referred through the Standards committee to the American Standards Association.

Plans for an afternoon session on metallic rectifiers, to be held during the 1947 winter meeting, also were discussed. It is expected that ten or more papers will be available for selection for that session.

These notes were furnished by E. A. Harty (M '36) secretary of the committee, for L. O. Grondahl (M '42) chairman.

POWER GENERATION

Disposal of a number of subcommittee reports chiefly occupied a luncheon meeting of the committee on power generation held June 27 in the Book-Cadillac Hotel. A. J. Krupy (M '33) presided.

M. J. Steinberg (M '32) of the joint committee on prime mover speed governing specifications reported that the committee is reviewing a specification for governing of steam turbines under 10,000 kw. A specification covering speed governing and pressure regulation is completed and will be distributed for comment in the near future. The draft of a specification for hydroelectric units is under preparation.

It was announced by A. D. Caskey (M '45) of the subcommittee on grounding practices that replies to its questionnaire are being received and a summary of their contents is being made.

After a discussion on whether a report on the standardization of excitation systems should be started now or deferred until after the educational process now under way is completed, it was voted to activate a subcommittee on standardization of excitation systems. It was agreed to continue the present subcommittee on excitation systems for the purpose of procuring papers.

A widespread interest in the application of the theory of probability to problems in system planning was noted by Mr. Steinberg, who thereupon was appointed to investigate and report on the potentialities of papers on this subject for a future meeting.

Sessions on hydroelectric systems and on interconnected systems are being planned tentatively for the 1947 winter meeting, it was announced. Notes on the meeting were submitted by Mr. Steinberg, secretary of the committee on power generation.

TRANSFORMER DIELECTRIC TESTS

The initial meeting of the working group on revision of dielectric tests, of the AIEE transformer subcommittee, was held June 26 for the purpose of defining the scope of its project. It was decided that the principal objective of the work would be the development of a set of tests which will assure that the assigned insulation levels have been met through proper design, and not through good workmanship alone.

The nature of the tests required, and the degree to which present tests meet the requirements, will be subjected to critical examination in the hope that simplification or better co-ordination can be achieved. Service requirements will be reviewed within the framework of the established basic insulation levels.

The foregoing notes were furnished by E. R. Whitehead (F '45).

Future Meeting Plans Include Midwest Meeting

A change in the number of yearly AIEE meetings was approved by the board of directors at its meeting June 27 in the Hotel Statler, Detroit, Mich. The locations of the meetings for the coming year also were settled by the directors.

It was decided that there will be four national meetings of the Institute each year, instead of the present three. The additional meeting will be known as the Midwest meeting. Section 27 of the bylaws was amended to read:

Section 27. There shall be four general meetings of the Institute each year, namely, the winter meeting, the summer meeting, the Midwest meeting, the Pacific Coast meeting, with such additional meetings as may be authorized from time to time by the board of directors. The board of directors shall determine the location and dates of all Institute meetings and, in case of public emergency, may postpone or omit any such meetings.

In accordance with recommendations submitted by the committee on planning and co-ordination and in acceptance of invitations received from the Sections involved, the following meetings were authorized:

1947 summer meeting, Montreal, Quebec, Canada, June 9–13.

1947 Midwest meeting, Chicago, Ill., exact dates in October to be determined later.

1948 winter meeting, Pittsburgh, Pa., January 26–30.

1948 summer meeting, Mexico City, Mexico, exact dates to be determined later.

The location of the 1947 Pacific Coast meeting still is under consideration. The board approved the dates, September 23–25, 1947, for the previously authorized Middle Eastern District meeting to be held in Dayton, Ohio.

No More "Conventions" for Institute. At its recent meeting in Detroit during the summer convention, the board of directors voted to drop the word "convention" in favor of the word "meeting" in designating the general meetings of the Institute. The first meeting affected by the change is the Pacific Coast meeting in Seattle, Wash., August 27–30, 1946.

Seventh Report Submitted on AIEE Aeronautical Standards

The air transportation committee, under the chairmanship of J. D. Miner, Jr. (M '42) has several subcommittees, each handling standardization activities, and this report summarizes the results to date. There is much work yet to be done, and the committee is very anxious to obtain some additional assistance from the aircraft industry in carrying on its standardization projects. Reports of the subcommittees follow.

Aircraft Electric Systems [Chairman, R. H. Kaufmann (M '41)]. The status of this work remains the same as it was in April. A comprehensive outline has been prepared covering the fundamental electrical problems involved in aircraft electric systems, characteristic data, procedures for analysis of system performance, and application practices. Data for a number of the sections have been compiled in preliminary form from various sources, and it is proposed to issue a report in preliminary form as soon as information is obtained covering the other sections.

Aircraft Electric Rotating Machinary [Chairman, M. L. Schmidt (M '43)]. A test code for "Aircraft D-C Machines" has been prepared, approved by the subcommittee, and has been sent to the air transportation committee for letter ballot approval as a proposed standard as of July 2.

Aircraft Wire and Cable (Chairman, W. S. Hay). As a result of extensive tests and studies, data have been obtained suitable for a preliminary test code for aircraft cables, and this is to be made available for committee consideration. AIEE paper 46-145, "Short-Time Current Ratings for Aircraft Wire and Cable," by B. W. Jones and J. A. Scott, presented at the AIEE summer convention, gives a method of evaluation of certain types of aircraft cables.

These data will be combined with other cable information in the afore-mentioned test code. This subcommittee is being discontinued, and the cable activities are to be incorporated into the subcommittee on control and protective devices, which will prepare a test code.

Aircraft Electric Control and Protective Devices [Chairman, R. A. Millermaster (M '34)]. This group has been awaiting the results of the work of some of the other groups. It is planned, in consolidating with the cable group, that the scope will be expanded to include cables as well as protective equipment, and this should be a very effective handling method, as the problems are allied closely. This added responsibility will necessitate reorganizing the subcommittee somewhat.

Aircraft Carbon Brushes [Chairman, V. P. Hessler (F '43)]. The major items which should be included in an aircraft machine carbon brush test code have been listed and divided into two groups: (1) those in which the technical progress is such as to warrant preparation of a preliminary test code, and (2) those items on which further research and development work will be required before a suitable test code can be prepared. The items of group 1 have been assigned for preparation, and it is expected that this material will be available for preliminary discussion at a meeting in January 1947. Preliminary copies of the proposed test code will be circulated to the industry for consideration as soon as available. The work of the carbon brush group is being consolidated with that of the aircraft d-c machinery subcommittee.

Basic Principles of Aircraft Altitude Rating [Chairman, W. E. Pakala (M '45)]. This subcommittee is just getting organized and expects to develop a standard covering the basic principles of altitude rating of aircraft electric machinery. This group contemplates studying the effect of temperature on insulation life, air density for flight ambient, blast tube cooling, methods of measurement and test, and standard methods of indicating rating as a function of altitude. This subcommittee is particularly in need of members who are associated with aircraft users. Suggestions concerning such membership will be welcomed by Mr. Pakala (Westinghouse Electric Corporation, East Pittsburgh, Pa.).

Aircraft D-C Apparatus Voltage Rating (AIEE 700). The results of the letter ballot concerning this Standard which has been out on a trial basis for over a year were inconclusive. It is planned to recirculate the industry and possibly to continue for an additional trial period with the proposed Standard 700 modified editorially.

Collaboration With SAE, NASC, and NEMA. It will be recalled that the AIEE aircraft electric standardization activities are being carried on co-operatively with other aircraft standardization work by other organizations such as the Society of Automotive Engineers, the National Aircraft Standards Committee, and the National Electrical Manufacturers Association. These other organizations are looking to the AIEE particularly for assistance in the formulation of fundamental electrical standards, including methods of rating and performance characteristics of electric equipment and devices, test codes and methods of demonstrating specified performance, determination of fundamental characteristics of aircraft electric systems and methods of calculation.

SAE Committee A-2—Aircraft Electric Equipment. This committee at a recent meeting reaffirmed its request to AIEE for assistance and also has requested information concerning additional projects. The members of the AIEE air transportation committee plan to schedule future meetings immediately adjacent to or concurrent with the meetings of SAE committee A-2 in view of the board mutual interest in these standardization activities and the large number of individuals who are interested in both groups.

Mailing Date Changed for Electrical Engineering

Hereafter, members and subscribers should receive their copies of *Electrical Engineering* by about the first of the month of issue, instead of three weeks or so later, as has been the unsatisfactory average during recent years.

Originally contracted for mailing between the 3d and the 5th of the month of issue, copies came to be mailed as late as the 23d, under the adverse influence of wartime and other conditions affecting the printing plant.

This seriously impaired the timeliness of material accepted under contract closing dates designed for the earlier mailing. Failure of consistent efforts during the past year to regain the original mailing dates left no alternative but to accept the later mailing dates, and to change the date designation of the issue and alter the contract closing dates accordingly.

Thus, effective with the October issue, the contract mailing dates will be the 20th–22d of the month, and members should receive their copies thereafter as promptly as the United States mails can carry them from the printing plant in Easton, Pa.

To effect this change with minimum lost motion and production confusion, and to avoid the impossible task of publishing two separate issues in the production time of one, the current August issue has been consolidated with the September issue.

Board of Directors Meeting Held in Detroit

The regular meeting of the AIEE board of directors was held in Detroit, Mich., June 27, 1946, during the summer convention. The morning session was held in the Hotel Statler and the luncheon and afternoon session in the Book Cadillac Hotel.

The directors appropriated $875 to cover the Institute's share of the cost of issuing the proposed "Fifteenth Anniversary Brochure" of the Engineers' Council for Professional Development; increased the official allowance for traveling expenses from nine cents per mile one way to eleven cents, effective August 1, 1946; and authorized the transfer of $40,000 from the general funds to the reserve capital fund for investment. Chairman W. R. Smith of the finance committee reported monthly disbursements of $47,136.94 in May, and $33,921.18 in June.

Mr. Smith reported that it was proposed to send a general letter to the members in Allied countries who became delinquent in the payment of dues during the war and were placed on the inactive list, suggesting that they become reinstated to active membership during the present fiscal year, without formality. It is proposed to send a similar letter to the members who were in military service and are still on the inactive membership list after they have had adequate time to communicate with headquarters. However, requests for restoration to active membership are received daily.

Meeting plans discussed and approved by the directors will be found on page 407.

After a further discussion of the possibility of an electrical exhibit being held concurrently with the winter meeting, the directors decided that no change should be made in Section 29 of the bylaws, and voted to clarify its action at the May meeting to read as follows:

> The board of directors of the AIEE sees no objection to the use by an exhibiting agency of the expression "To be held concurrently with an AIEE meeting."

The steps previously taken for co-operation with the 1946 National Electronics Conference were reviewed, and the committee on planning and co-ordination was requested to report upon the question of continuing official co-operation.

Section 65 of the bylaws was amended to include the new standing committee on registration of engineers, and a new Section 73 was adopted to define the scope of the committee, reading as follows:

> Section 73. The committee on registration of engineers shall consist of 9 members, appointed by the president. This committee shall keep informed on registration laws and amendments thereto, and shall co-operate with other societies and various examining boards. The committee shall submit reports and recommendations regarding registration to the board of directors for such Institute action as appears to be in the best interests of the engineering profession and the community.

In accordance with the directors request at its May meeting, the committee on planning and co-ordination had given consideration to the possibility of greater use of the District organizations and to methods of planning visits to Sections to make more effective use of the president's time. The committee recommended and the directors adopted the following resolutions:

> RESOLVED that it is the sense of the board of directors that:
>
> (a). Attendance of the president at general meetings,

District meetings, meetings of the Engineers Joint Council, and other intersociety obligations should take precedence over visits to Sections.

(*b*). The District vice-president shall be made fully responsible for the visits to local Sections. It shall be the duty of the District vice-president to receive all requests for Institute officer speakers and to co-ordinate these requests for all meetings in his area. If the District vice-president is not to make the visits personally, he may be free to arrange for other officers, or members of the headquarters staff, to be the official delegate when this appears to be the most effective method.

(*c*). At each summer meeting, it shall be the duty of the secretary of the Institute to call a special meeting of the hold-over and incoming vice-presidents at which they shall be informed of their duties in co-ordinating the work in the Districts and instructing Sections on the method of obtaining officer speakers.

(*d*). When the formal visits to Sections are made by either the District vice-president or by some other officer, the same expense allowance will be paid by the Institute as if the visits were all made by the vice-president.

(*e*). The committee on planning and co-ordination is requested to continue its study of the possibility of greater use of the District organizations.

RESOLVED, that the attention of the Districts be called to the merits of building the program of a District meeting around a dominant theme based on a subject of timely interest and particularly suitable to the location in which the meeting is to be held; that when this type of program is contemplated the committee in charge of a District meeting should at the earliest opportunity notify the secretary of the technical program committee in order to take advantage of the assistance which is available to them in the appropriate technical committee or committees, the technical program committee, and the headquarters staff, and that such an occasion might well afford a favorable opportunity for a meeting of the interested technical committee or committees. It is to be understood that a District meeting is the responsibility of the District concerned and hence that the initiative in planning and arranging for a meeting of the type suggested lies with the District executive committee.

The committee on collective bargaining and related matters made the following recommendations:

1. That the publication of the "Manual on Collective Bargaining for Professional Employees" be a joint undertaking of the several societies (at present six) participating in the work of the Committee on Economic Status of the Engineer.

2. That the AIEE committee on collective bargaining and related matters continue to develop the draft of the complete manual with the understanding that the drafts of the outline, and of the several chapters, are to be submitted to the Committee on Economic Status of the Engineer for criticism as they become available.

3. That the program be changed to provide for the earliest practicable issuance of Part I of the manual as a separate publication.

The directors approved these recommendations, and also approved the publication of Part I of the manual on the basis of the outline presented by the committee.

It was reported that the United Engineering Trustees, Inc., had recently approved the appointment of a building planning committee composed of the four secretaries of the Founder Societies, or their designees, the secretary of UET, a representative of the library, and the president of UET as chairman.

The secretary of the AIEE was authorized to serve on this committee, provided this is not construed to preclude consideration of a possible new building.

At the recommendation of the Engineers Joint Council the board voted that the president of AIEE be authorized to appoint a representative to serve on a panel which would be represented at hearings on the Bloom Bill, HR 4982. EJC is opposed to the bill which would empower the State Department to engage in a broad program of dissemination of information in foreign countries, and the interchange of persons, knowledge, and skills between the United States and other countries.

President Wickenden reported that he had appointed Everett S. Lee as AIEE representative on the American committee on participation in the Sixth International Congress for Applied Mechanics.

Present at the meeting were:

President W. E. Wickenden; Past President C. A. Powel; Vice-Presidents C. B. Carpenter, M. S. Coover, J. F. Fairman, E. S. Fields, R. T. Henry, F. L. Lawton, L. M. Robertson, R. W. Warner, H. B. Wolf; Directors P. L. Alger, J. M. Flanigen, K. L. Hansen, C. M. Laffoon, C. W. Mier, S. H. Mortensen, W. B. Morton, J. R. North, D. A. Quarles, Walter C. Smith, W. R. Smith; Treasurer W. I. Slichter; Secretary H. H. Henline; and by invitation, incoming officers, J. Elmer Housley, R. F. Danner, E. W. Davis, T. G. LeClair, E. P. Yerkes; also, for a part of the meeting, M. M. de Lascurain (Mexico Section delegate), I. Melville Stein, K. B. McEachron, J. E. Hobson.

DISTRICT • • • • •

Great Lakes Meeting in Indianapolis, October 9–11, 1946

To secure better hotel facilities and to avoid conflicts of meetings the location for the Great Lakes District meeting has been shifted to Indianapolis, Ind., and the dates have been changed to October 9–11, 1946. Both the Fort Wayne Section and the Central Indiana Section will be hosts to the meeting.

An industrial type of program will be featured, and most of the papers will be conference presentations. The subjects of sessions tentatively arranged are as follows: power transmission and distribution, basic sciences, electronics, quality control, industrial measurements, communications, industrial power applications, and industrial control.

STANDARDS • • •

Pool Cathode Mercury-Arc Converters. There is now available for comment and criticism a "Report on Proposed Standard for Pool Cathode Mercury-Arc Power Converters." This report, 6, in the AIEE Standards series, was prepared under the auspices of the subcommittee on electronic power converters of the AIEE committee on electronics. Doctor C. H. Willis, chairman of the subcommittee, is also chairman of the American Standards Association Sectional Committee C34, Mercury Arc Rectifiers, to which the report will be presented for consideration. The AIEE is sponsor for C34. These Standards apply to all types of mercury-arc power converters, employing rectifying devices with mercury pool cathodes and used for power conversion purposes, including mercury-arc power rectifiers, mercury-arc power inverters, electronic frequency changers and converters used with electronic motors when these equipments employ mercury-arc rectifying devices with pool cathodes. These Standards do not apply to welding rectifiers, nor electronic power converters employing rectifying devices with thermionic cathodes. Due to the action of the rectifier, the windings of associated transformers carry currents which differ substantially from the usual sinusoidal form. These Standards, therefore, include a supplement on transformer equipment of rectifier units. Copies of the proposed Standard, which supersedes the edition of 1934, can be obtained from AIEE headquarters without charge.

Symbols for Electric Power and Control. A recently revised edition of the American Standard Z32.3 "Graphical Symbols for Electric Power and Control" is now available at 40 cents per copy with the usual 50 per cent discount on single copies to members of AIEE. This revision was approved by ASA on March 1, 1946.

Neutral Grounding Devices. A subcommittee of the AIEE committee on protective devices, under the chairmanship of J. E. Clem (F '38), has prepared a revision of the AIEE 1942 report 32 on "Neutral Grounding Devices." This revised report has been recommended by the protective devices committee for approval as an AIEE Standard. After the period required for obtaining necessary formal approval, notice of its availability will be given in *Electrical Engineering*.

Machine Tool Wiring Standards. As the result of an appeal from the AIEE Cincinnati Section that the Institute interest itself in what probably would result in the development of a recommended practice for the application of electric equipment to machine tools, the Standards committee at its meeting of June 25 took action recognizing the importance of such a project. It directed that an investigation be made of any past or current work of a similar nature and, if such is in progress, that request be made for proper representation in a further development of the project. With this object in view, the committee on industrial power applications is studying the situation with a view to later definite recommendations on action by the Institute.

Voltages Under 100. Sectional Committee C67, working under the sponsorship of the electrical Standards committee of ASA has completed work in the preparation of a proposed Standard for trial use on "Voltage Under 100." At the present time it is not known when this will be available for distribution.

Storage Batteries. The Institute, as sponsor for Sectional Committee C40, Storage

Batteries, is reorganizing that committee with a view to undertaking a revision of the American Standard for "Storage Batteries," AIEE 36, approved in 1928.

Hard Drawn Aluminum Conductors. The American Standard C11 for "Hard Drawn Aluminum Conductors" was approved in 1927. Steps now are under way to reorganize the C11 committee. When such reorganization is completed, the work of revising the Standard will be undertaken largely from the viewpoint of additions to the Standard to cover recent developments.

Definitions of Electrical Terms. Sectional Committee C42 under the sponsorship of the AIEE developed the "American Standard Definitions of Electrical Terms" approved by ASA in 1941. It also was approved as a Canadian standard in 1942. Due to pressure of war work the sectional committee has been inactive since 1942. Over 20,000 copies of C42 have been put in circulation. In the interim, however, headquarters has been in receipt of some criticisms of the approved definitions and a large number of suggested additions. Due to the long period of inactivity it has been found necessary to reorganize the sectional committee completely. This work is practically complete. As soon as a new chairman to succeed C. H. Sanderson, resigned, has been selected, the work of setting up the 18 subcommittees will be undertaken, and it should be possible to get the actual work of revision under way early in the fall.

(Left to right) J. A. Rawls (M '27) outgoing chairman of the AIEE Virginia Section, J. E. Housley (F '43) AIEE president, and C. H. Smoke (M '42) incoming chairman of the Virginia Section, at the recent annual convention of Virginia engineers, the first since 1941. The convention, a two-day affair sponsored jointly by the various engineering organizations in Virginia, was held at the Hotel Nansemond, Norfolk, Va. AIEE representatives on the meeting committee were: Llewellyn Saunders (M '32) and H. W. Evans (M '34)

SECTION • • • • • •

Well-Planned Service for Veterans Offered by New York Section

The program of weekly conferences for returning veterans instituted by the New York Section in December 1945 aroused a great deal of interest at the conference on student activities held in Detroit, June 27.

The veterans committee of the New York Section was created to advise returning veterans on their educational and employment problems in an informal way with the co-operation of the Institute of Radio Engineers and the Illuminating Engineering Society. Although so far the committee has attempted to cover only branches of electrical engineering, many mechanical engineers have attended the conferences. Subsequent interviews were arranged for these men.

The meetings scheduled for 7 p.m. each Thursday evening are publicized by bulletin board notices in termination centers, other veteran service centers, and in the Engineering Societies Personnel Service.

A diversified group of counselors usually is in attendance and to expedite counseling a brief questionnaire is filled out by the veterans, giving their war record, principal experience, and previous schooling. The nature of the committee then is explained, and the educational and employment situation is outlined in a general manner. Each man is given a list of engineering schools and curricula accredited by the Engineers' Council for Professional Development and a copy of the most recent employment bulletin of the Engineering Societies Personnel Service, Inc.

Assignments to counselor groups then are made on the basis of field of interest, though the men are encouraged to visit any of the other groups, as they wish. The counselors who have volunteered report thoroughly enjoying the experience because of the seriousness of purpose and high caliber of the veterans.

By June 13, 27 conferences had been held, and 42 different engineers had acted as counselors. The veteran attendance had varied from 8 to 50 and had totaled 705. The counselor attendance had varied from 3 to 12 and had totaled 150. The veterans have expressed gratitude for this service, and the Section has had a favorable reaction from the various service centers.

Continual Education Program Followed by New York Section

In furtherance of the efforts of the AIEE committee on education at the Detroit summer convention conference of officers, delegates, and members to stimulate greater educational activity among the Sections, the New York Section has submitted some pertinent statistics on its ventures into the educational field since 1934.

The educational work of the Section commenced in 1930, at which time a course in public speaking was offered by the power group. A course in effective speaking since has become a fixture in the Section's seasonal programs. It was not until 1934, however, that technical courses were given consistently. The custom of having the courses sponsored by technical groups, of which the New York Section has six, has continued. In many instances the courses have been sponsored co-operatively with local units of other national societies—the Institute of Radio Engineers, the Illuminating Engineering Society, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Mathematical Society, the American Physical Society, and the American Society of Civil Engineers.

During the past year, courses have been organized by the power and industrial group and by the groups on communications, basic science, and illumination. The lecturers are drawn from industry and from the colleges. For recent courses, classroom facilities in Columbia University and Pratt Institute have been secured, as well as lecture rooms in the Engineering Societies Building and in a number of company properties in the New York area.

The length of the courses ranges from 18 to 3 weekly sessions, and the fees from $15 to $1 for members. A six-week course with a $3 fee is the most common arrangement. The fee usually is doubled for nonmembers, but the difference in tuition is refundable if application for membership is made within a specified time.

With ten engineering colleges in its territory, the Section carefully has avoided encroachment on academic curricula. Continuation of college work by members, especially graduate work, has been encouraged. Fifty different subjects have been covered, some so popular that they have been repeated yearly for 12 years. Typical of their kind are the following courses from the 1945–46 list: atomic engineering, applied lighting, engineering economics and practice, structural planning and design, radar, electric power utilization, transformers, rectifiers, servomechanisms, induction and dielectric heating, and cables. Courses mainly fall into two classes:

1. Review courses for men preparing for profesional engineer's license examinations.

2. Information courses covering developments and review of engineering techniques.

The total enrollment through the 1945–46 season has exceeded 13,100. A breakdown of this figure indicates the distribution of interest:

1. Electronics and related courses	4,500
2. Review courses for licensing examinations	3,700
3. Courses of special interest to industrial engineers	1,700
4. Public speaking courses	500

ABSTRACTS

TECHNICAL PAPERS previewed in this section will be presented at the AIEE Pacific Coast meeting, Seattle, Wash., August 27–30, 1946, and will be distributed in advance pamphlet form as soon as they become available. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Mail orders will be filled
AS PAMPHLETS BECOME AVAILABLE

Air Transportation

46-180—Control and Protection of Aircraft Power Systems; *B. O. Austin* (*M '42*). *15 cents.* Control and protection of aircraft d-c power systems are described pointing out the wide differences in the generator capacities of prewar and postwar transports. Consideration is given to the new wide speed generators having three to one ratios and capable of sustaining fault currents from 5,000 to 10,000 amperes at a voltage of 30 or greater. Control devices involving performance, over-voltages, and generator and cable faults are discussed. Diagrams showing the various degrees of protection are provided, together with actual photographs of the apparatus. A means of quick removal of the control panels is shown.

46-188—An Electronic Frequency Meter and Speed Regulator; *Ellis Levin* (*A '44*). *20 cents.* An electronic frequency meter and speed regulator has been devised to measure and hold the speed of a small air or steam turbine within plus or minus one half per cent of any speed between 10,000 and 100,000 rpm. It employs a photoelectric speed pickup, a null-balance frequency measuring circuit, and an electropneumatic servomechanism. The frequency meter, of the modified "recurrent capacitor discharge" type, provides a d-c or an a-c error voltage proportional to variation of the input frequency from the desired value, with a frequency measuring accuracy in the order of one tenth per cent.

46-190—Electrical Anti-icing of Aircraft Windshields; *J. D. McCrumm* (*A '36*). *20 cents.* The primary purpose of heating an aircraft windshield is to prevent ice formation. If, in addition, the windshield is of laminar glass and vinyl plastic construction, the resistance to bird impact may be increased substantially by maintaining a normal temperature. This paper discusses windshield thermal requirements as a function of flight environment and factors pertinent in designing a heated structure. The heat may be supplied by heated air, resistance wires embedded in the plastic, infrared radiation, or a transparent electrically conductive coating on the glass. The heated air system requires two panels and may develop excessive vinyl temperatures; however, the anti-icing ability is good, and the weight not excessive. Hot embedded wires produce serious optical distortion but offer a lightweight system. The infrared equipment is very awkward to install. The transparent coating, a very thin but durable film of low electrical resistance applied to glass, offers considerable promise as the best solution to the problem.

46-192—An Improved Azimuth Indicating System for Aircraft; *E. E. Lynch* (*M '35*). *R. A. Pfuntner. 20 cents.* Because of the violent maneuvering possibilities in modern aircraft, the usefulness of azimuth indicators in avigation depends on circumstances not existing in marine navigational applications. New problems in direction indicating instruments therefore have been introduced, such as the perplexing problem of obtaining indication after loops, rolls, and so forth. Azimuth indicating systems now used in aircraft have not given a completely satisfactory solution to such problems. This paper sketches progress from the direct reading compasses to monitored gyroscopes and concentrates on the unique problems in aircraft where space limitations, reliability, and operation at all altitudes are important.

46-193—Effects of Thermal Characteristics of Aircraft Generators on Load Analysis; *Stanley Rogers* (*A '43*). *20 cents.* The large and complex electric systems in modern, long range aircraft have made accuracy of load analysis more important than ever before. By averaging anticipated loads over not one or two, but several different periods of time, the adequacy of proposed generators can be evaluated more precisely. The generators' overload thermal characteristics are the primary factor in determining the lengths of the different averaging periods. Overload characteristics may be determined experimentally, or may be estimated by a combination of mathematical and empirical relations, and may be represented graphically by a "permissible overload curve." Such a curve states the time for which, under specified conditions, an overload of any magnitude can be tolerated by a stated generator. Direct graphical comparison of anticipated average loads with the permissible overload curve clearly indicates the adequacy of proposed generating equipment.

46-197—150,000 Horsepower Applied to Aeronautical Research; *J. A. White* (*A '41*). *15 cents.* This paper describes applications of electric power at the Ames Aeronautical Laboratory of the National Advisory Committee for Aeronautics. This aeronautical research laboratory at Moffett Field, Calif., has wind tunnels and accessory equipment, in operation or under construction, aggregating over 150,000 connected horsepower, with as much as 50,000 horsepower in a single drive unit. The "modified Kraemer" variable-speed drive system, an a-c variable-speed system particularly suited for large-power applications, is described, as well as other types of wind tunnel drive systems. The applications of special water-cooled motors for driving propellers on airplane models is discussed. Power is delivered to the Ames laboratory at 110,000 volts and is stepped down to 6,600 volts for the large wind tunnel drives and for distribution to buildings. Owing to the intermittent operation of wind tunnels, power dispatching is practiced in order to avoid unnecessarily high maximum demands due to occasional simultaneous operation of large wind tunnels.

Basic Sciences

46-195—The Use of Business Machines in Determining the Distribution of Load and Reactive Components in Power Line Networks; *P. D. Jennings, G. E. Quinan* (*F '18*). *15 cents.* The object of this paper is to give a brief description of the use of punch card type of business machines in determining load and reactive component distribution in power line networks, when analyzer boards are not readily available. It is possible to determine such distribution by the solution of a set of simultaneous complex linear equations, which can be accomplished by the use of determinants. The business machines will eliminate the great amount of time and drudgery heretofore required in solving the determinants.

Communication

46-183—Application of Compandors to Telephone Circuits; *C. W. Carter, Jr.* (*M '39*), *A. C. Dickieson* (*M '41*), *D. Mitchell. 25 cents.* Prior to the war a compandor was developed for general use on broad band message circuits of the Bell System. This equipment provides power

range compression at the transmitting end and power range expansion at the receiving end of a telephone channel. The resulting cross-talk and noise reductions of about 25 decibels are large enough to make useful circuits out of channels which otherwise would be unworkable. The paper considers engineering problems in the application of compandors and describes the circuit principles involved in the equipment.

46-198—Television—A Review of Present Status; *E. W. Engstrom, R. D. Kell. 15 cents.* Before the war there were four major technical problems facing the commercialization of television:

1. Radio transmitters of adequate power to cover all of the commercial broadcast channels.
2. Television broadcast networks.
3. Sufficient television camera sensitivity.
4. Larger and brighter pictures.

The present technical status of television is described. This includes a description of the solutions to the four technical prewar television problems.

Domestic and Commercial Applications

46-184—Specific Engineering Problems in Rural Electrification and Electroagriculture; *M. M. Samuels (F'24). 30 cents.* In the fields of rural electrification and electroagriculture, there are specific problems for the electrical engineer, some old, some new, some partly solved, others as yet unsolved, and still others which have not yet been definitely stated. This paper discussed representative problems in the various categories. Co-operative efforts by industrial, educational, and governmental agencies in solving specific problems are described. Problems not yet solved or not yet definitely stated are presented as a challenge to the profession. An appendix contains a list of applications of electricity for the farm.

Education

46-187—Teaching Electricity and Magnetism; *V. P. Hessler (F'43). 20 cents.* The fundamental relations of electricity and magnetism are presented in a series of experimental, defined, and derived relations and generalizations. Each succeeding relation is shown to result from derivation based on the preceeding relations or to be the result of additional experiment or definition. All relations contain the fundamental constants—permeability of free space and permittivity of free space—and thus are applicable to any unrationalized unit system. All magnetic field quantities are shown to be the result of definition. The rationalized system of relations can be formed in a similar manner by arbitrarily replacing the number 2 in the numerator of the parallel wire force equation by a 2π in the denominator.

Electric Machinery

46-189—Dielectric Strength of Station and Line Insulation to Switching Surges; *P. L. Bellaschi (F'40), L. B. Rademacher (A'45). 20 cents.* The paper reports tests conducted to determine the strength of station and line insulation to switching surges and analyzes the findings with respect to prior data in relation to the overall insulation problem. In most cases, impulse data were secured simultaneously for comparison purposes. The switching surges developed in the tests attain durations in excess of 1,000 microseconds and voltages corresponding to five times line-to-neutral voltage on a 230-kv system, or $3^1/_2$ times on 345 kv. Tests were made on apparatus both dry and wet comprising insulators, bushings, and rod gaps. In addition, tests were conducted on oil-immersed apparatus. The switching-surge strength of station and line insulation, in most cases, is 90 to 95 per cent of the corresponding impulse. For insulation in air conforming to usual conditions, the switching-surge strength is not affected by rain or dew to a greater extent than impulse. These fundamental data should be conducive to better utilization of the insulation and of significance in connection with developments of power transmission at extra-high voltages.

Industrial Power Applications

46-194—Self-Excited Electromagnetic Drive for a Resonant Fatigue Machine; *A. R. Willson (M'35). 15 cents.* This paper describes the application of a self-synchronous vacuum tube drive to fatigue testing machines. Fatigue machines simulate the vibrating loads which result from reciprocating engines, variable air loads, and various rotating machinery which is not properly dynamically balanced. The electric drive is a solenoid operating in a polarized field similar to a loudspeaker. The exciting voltage is generated synchronously with a vibrating beam of the machine. This voltage then is amplified sufficiently to drive the actuator solenoid synchronously. This self-synchronous feature is very important, because the inherent high Q of the system amplifies some 10 to 50 watts of drive power into 2,000 to 5,000 pounds of vibrating load at frequencies from 7 to 40 cycles per second. An experimental 5,000-pound machine is described in this paper. This electric drive is comparatively low in original cost and cheaper to maintain than mechanical types previously used. The specimen load is controlled as simply as the volume on a radio receiver. A 100,000-pound fatigue machine which is nearing completion, is described briefly.

Instruments and Measurements

46-179—Fault-Current Measuring Device; *M. J. Lantz (A'43). 15 cents.* In electric power system operation, numerous problems are encountered in analyzing the results of short circuits and in the physical location of the trouble. The device described in this paper is a simple, automatic, inexpensive, and reasonably accurate piece of equipment for measuring the magnitude of fault current. The results of a number of laboratory and field tests show accuracies of the following order: maximum deviation ± 12 per cent and an average deviation of ± 5 per cent. The device consists of one or more coils of wire with magnetic links inserted in them. The contacts of a by-pass relay normally short-circuit the coils until approximately one cycle prior to the oil circuit breakers' interruption of current. The device is placed in the secondary winding of the current transformers and records the magnitude of the last one-half cycle of fault current prior to its interruption. The device can determine the magnitude of the fault current, the type of fault, and phases involved.

46-181—An Oscillograph for Recording Transient Recovery Voltages; *W. G. Hoover (A'34). 20 cents.* In this oscillograph, which uses a high-voltage sealed-off cathode-ray tube, the beam is swept horizontally across the fluorescent screen once for each current zero during the interruption process. Voltage across the test circuit breaker causes vertical deviations of these traces. The individual horizontal sweeps are separated by superimposing them on a slow downward drift. A series of spaced lines results, with the last and lowest line containing the recovery-voltage transient at arc extinction. Timing the high-speed horizontal sweeps is accomplished by a d-c biased saturating core tripping transformer connected to a current transformer measuring the short-circuit test current. A camera attachable to the front of the oscillograph photographs the traces on the screen and also allows simultaneous visual observation. Oscillograms obtained on high and low power interruption tests are shown.

Land Transportation

46-186—Comparisons of Railway Motive Power for Operations in the Pacific Northwest; *T. M. C. Martin (A'45). 30 cents.* This paper analyzes modern reciprocating steam, Diesel, and electric locomotives for operation in the Pacific Northwest. Physical comparisons in terms of the respective hauling abilities of different locomotives as well as economic comparisons of their operating capabilities are included. The principal conclusion reached is that, although the first cost of full electrification is greater than full Dieselization, the operating facility provided not only is capable of maximum physical accomplishment but also gives more assurance of continued satisfactory economic performance. This is true under existing price levels of Diesel oil and electric energy, and the choice of electrification is no less attractive when full consideration is given

to the probable future relative prices of energy sources. In a region of extensive hydroelectric development, mainline electrification well may afford railroads a hedge against undue inflation of operating costs during the next decade or two.

Power Generation

46-178—Power System Development for Service to Hanford Plutonium Plant; *B. V. Hoard* (*M* '36), *J. R. Curtin* (*A* '42). *20 cents.* Early in 1943 it became known that the Hanford Engineer Works load would be connected to the power system of the Bonneville Power Administration. Only after the war was won, was it learned that this plant was making plutonium for use in atomic bombs. However, initially it was known that whatever the product made, this plant would require a power supply which would have the utmost reliability. At that time many other war loads were being supplied by the BPA system, but, because of shortage of materials and labor, system additions had not kept pace with the new war loads. As a result, the system could not supply reliable service to the Hanford Engineer Works without major additions and system changes. This paper describes various interesting problems encountered, the methods used, and the changes made in the BPA system, so that the Hanford Engineer Works would have a reliable source of power supply.

46-182—Long-Distance Power Transmission as Influenced by Excitation Systems; *C. Concordia* (*M* 37). *S. B. Crary* (*F* '45), *F. J. Maginniss* (*A* '43). *30 cents.* The object of this paper is to show how the electric loadings of long-distance transmission systems may be increased appreciably by the use of automatically controlled excitation and the proper co-ordination of apparatus characteristics. A reconsideration of this problem has been made desirable by the development of the continuously acting static type of voltage regulator and by the present ability to determine power limits more accurately through the use of network and differential analyzers. Two of the principal conclusions to which the present studies have led are that some benefit may be realized by using high rates of excitation response for sufficiently mild faults, or three-phase faults of very short durations, and that special intermediate low-transient reactance synchronous condensers, with properly co-ordinated regulators and excitation systems, can provide a practical method for increasing the stability limits of long single-circuit lines.

46-185-ACO—Columbia River Power; *E. I. Pease* (*M* '29), *H. W. Goodhue. 20 cents.* Prime power potentiality of the Columbia River system is about 50,000,000 kw, or twice the present average output of the nation. A third or more of this may be developed economically. Planning for comprehensive development of the river for power and all other beneficial purposes is a tremendous undertaking in which many agencies are participating. River regulation by storage and power co-ordination throughout the basin will be essential elements of that development. The power load has grown phenomenally in this region, nearly trebling in the last ten years, and early need for much greater hydroelectric installation is expected. Load characteristics will be important in the selection and design of projects. Large generating units generally will be advantageous.

46-191-ACO—Design Factors to Promote Reliability of Hydroelectric Station Auxiliaries; *C. L. Killgore* (*A* '37). *15 cents.* Operation of a hydroelectric generating unit is dependent at all times upon the performance of its auxiliaries. The design of the electric distribution system and all other equipment associated with operation of hydroelectric station auxiliaries, as well as the auxiliaries themselves, must provide maximum reliability and continuity of service. Proper consideration of six important design factors, described in this paper, has insured dependable auxiliaries for over 2,500,000 kw of hydroelectric generating capacity in more than 30 power plants of the United States Bureau of Reclamation.

46-201-ACO—Hydroelectric Power System Design; *S. M. Denton* (*A* '39). *25 cents.* This discussion is concerned with hydroelectric power plant design with particular attention given to the structures and the major machines and equipment. Its background is the design of power systems by the Bureau of Reclamation. The installed capacity of these systems approximates 2,500,000 kw. The hydroelectric power plants of the Bureau are located west of the 100th meridian in the arid and semiarid regions of the United States. Some of the problems peculiar to these multipurpose projects are outlined, especially the arrangement of the structures. Also some of the problems involved in the selection and designs for the major machines and equipment are discussed.

Power Transmission and Distribution

46-196—Characteristics of a 400-Mile 230-Kv Series-Capacitor-Compensated Transmission System; *B. V. Hoard* (*M* '36). *30 cents.* Several new and interesting problems arise when series-capacitor compensation is used to increase the stability and amount of power to be transmitted over a long high-voltage transmission system. The major factors involved in a compensated system are discussed, using typical 400-mile two-circuit lines with two intermediate series capacitor stations. Line loadings are assumed which are considerably higher than could be carried with transient stability over a similar system without series compensation. The effects of short-circuiting the capacitor units during system faults, and of delay in reinserting the capacitors after the fault is cleared, are analyzed with respect to system stability and with respect to the amount of series compensation to be used. Transients in a series *L-R-C* circuit are analyzed briefly, because such transients introduce new relaying problems in the compensated system. Various relaying schemes for line protection and for protection of the series capacitor equipment during line faults are considered.

Protective Devices

46-177—4,370,000 Kva Short-Circuit Tests on Grand Coulee 230 Kv-Bus; *W. H. Clagett* (*M* '46), *W. M. Leeds* (*M* '38). *20 cents.* The unusually large concentration of generating capacity at Grand Coulee Dam makes possible short-circuit power on the 230-kv bus considerably in excess of the rupturing capacity of circuit breakers now available at that voltage. Methods of sectionalizing the bus and segregating the transmission lines to limit the maximum short circuit to less than 3,500,000 kva are described in this paper. Three-phase faults up to 3,110,000 kva and single-phase-to-ground faults equivalent to 4,370,000 kv were cleared easily during a series of staged tests on a 230-kv 3-cycle 3,500,000-kva steel-tank oil circuit breaker. These tests confirm high power laboratory tests and suggest the practicability of constructing circuit breakers of still higher interrupting rating, the application of which would free the Coulee Dam system from present operating limitations.

46-199—Field Tests of Power Line Carrier Current Equipment; *R. H. Miller* (*A* '36), *E. S. Prud'homme* (*A* '42). *15 cents.* This paper describes a series of field tests made on the power line carrier current telephone system of the Pacific Gas and Electric Company. Some of the test methods are outlined, and test results are given. A comparison of frequency and amplitude modulated systems is made, and data showing the relative response to noise of frequency modulated and amplitude modulated channels are presented. Considerable data and curves are given showing the audio and carrier frequency characteristics of various parts of the carrier telephone system. Some of the requirements for satisfactory performance and limitations of power line carrier equipment are discussed.

46-200—Sensitive Ground Relay Protection for Complex Distribution Circuits; *L. F. Hunt* (*F* '38). *15 cents.* Protection engineers have been confronted with the problem of relaying ground faults on lower voltage circuits. This paper describes a method of isolating ground faults on complex feeders that has been in actual operation on the Southern California Edison Company's system for a period of six years. This method of relaying functions reliably on exceptional low values of ground current, with full ground faults limited to small values of current. This makes the operating range of ground relays up to ten times normal minimum trip current.

PERSONAL ....

C. J. Breitwieser (A '33, M '44) design engineer in charge of the radio electrical engineering department, Consolidated-Vultee Aircraft Corporation, San Diego, Calif., received the 1945 District 8 prize for initial paper for his paper, "Constant-Speed Drives for Aircraft Alternators." Born in Colorado Springs, Colo., in 1910, Mr. Breitwieser holds the degrees of bachelor of science from the University of North Dakota and master of science from California Institute of Technology. After two years as instructor at the University of North Dakota, Grand Forks, he was consulting engineer in Pasadena, Calif., from 1932 to 1935, and in the latter year he formed C. J. Breitwieser and Company, consulting engineering and manufacturing company. This company merged with another to form the Caldo Corporation in 1937. In 1939 he became consulting engineer for the De Forest Laboratories and in 1941 staff engineer for Consolidated-Vultee corporation.

E. W. Boehne (A '29, F '43) research engineer, general engineering division, General Electric Company, Philadelphia, Pa., received the 1945 best paper prize for District 2 as coauthor of the paper, "Anode-Circuit-Breaker Design and Performance Criteria." Born in 1905 in Laramie, Wyo., Mr. Boehne holds the degrees of bachelor of science and electrical engineer from the Agricultural and Mechanical College of Texas and the degree of master of science from Massachusetts Institute of Technology. He has been employed by the General Electric Company since 1926, at Lynn, Mass., and Schenectady, N. Y., as well as in Philadelphia, to which he was transferred in 1933. Mr. Boehne twice has received the Charles A. Coffin Award, In 1941 he was awarded the AIEE best paper prize for District 2 and in 1944 the national prize for the best paper in theory and research.

W. B. Buchanan (A '16, M '32) assistant laboratory engineer, Hydro-Electric Power Commission of Ontario, Toronto, Canada, has received the 1945 District 10 prize for best paper as coauthor of the paper, "Field Tests of Interrupting Capacity of 138-Kv Oil Circuit Breakers." Mr. Buchanan was born in Grey County, Ontario in 1885, and holds the degrees of bachelor of science and electrical engineer from the University of Toronto. He was a demonstrator at the University of Toronto from 1913 to 1916 and in 1916 assumed charge of general electrical testing in the laboratories of the Hydro-Electric Commission.

G. D. Floyd (A '19, M '28) electrical consultant, electrical engineering department, Hydro-Electric Power Commission of Ontario, Toronto, Canada, has received the 1945 District 10 prize for best paper as coauthor of the paper, "Field Tests of Interrupting Capacity of 138-Kv Oil Circuit Breakers." Mr. Floyd was born in Nova Scotia in 1892 and received the degree of bachelor of science from Dalhousie University and from McGill University. He also studied in the graduate school of Cornell University. He worked for a time in 1915 for the Westinghouse Electric and Manufacturing Company in East Pittsburgh, Pa. In 1919, after serving in the Royal Flying Corps in World War I, he joined the Hydro-Electric Commission. He was assigned to the Commission's laboratories until 1926 when he was transferred to the electrical engineering department.

E. C. Goodale (A '27, M '45) electrical engineer, Control Section, Bonneville Power Administration, Portland, Oreg., received the 1945 District 9 prize for best paper as coauthor of the paper, "Field Determination of Current Transformer Errors by the Secondary-Voltage Method." Mr. Goodale was born in Riverhead, N. Y., in 1898, and received the degree of mechanical engineer from Cornell University. After graduation he was cadet engineer with the Syracuse (N. Y.) Lighting Company and in 1925 went to Long Beach, Calif., for Stone and Webster Construction Company. He was relay and meter inspector with the Puget Sound Power and Light Company, at Tacoma and Olympia, Wash., from 1926 to 1940 and in 1940 became electrical engineer with the Bonneville Administration.

J. V. Kresser (A '32, M '43) district engineer, Westinghouse Electric Corporation, San Francisco, Calif., has received the 1945 District 8 prize for best paper for his paper, "Characteristics and Limitations of Transformer Connections." Mr. Kresser was born in 1904 in Noumea, New Caledonia. After his graduation from Massachusetts Institute of Technology, he was employed from 1930 to 1932 by the Westinghouse corporation at East Pittsburgh, Pa. From 1933 to 1937 he was associated variously with the Spreckels Sugar Company, Spreckels, Calif.; the Electrolift Corporation; and the Standard Oil Company of California, San Francisco. He became district engineer for the Westinghouse Electric Corporation in 1937.

J. L. Holbeck (A '24, M '36) chief of the meter unit of the operation and maintenance department, Bonneville Power Administration, Portland, Oreg., received the 1945 District 9 prize for best paper as coauthor of the paper, "Field Determination of Current Transformer Errors by the Secondary-Voltage Method." Born in Soudan, Minn., in 1897, Mr. Holbeck was graduated from the University of Minnesota in 1924. He was employed by the Minnesota Power and Light Company, Duluth, from 1924 until in 1938 he joined the Bonneville project as associate engineer.

W. B. Keller (A '41) electrical test and design engineer, Leece-Neville Company, Cleveland, Ohio, has received the District 2 prize for initial paper for 1945 for his paper, "Aircraft Regulators and Relays." Mr. Keller, who was born in Cleveland in 1917, was graduated from the Case School of Applied Science in 1940. He previously was employed by the Cleveland Electric Illuminating Company and is a member of the Society of Automotive Engineers.

F. W. Grover (A '21, M '30) professor of electrical engineering, Union College, Schenectady, N. Y., has retired. Doctor Grover, who was born in Lynn, Mass., in 1876, holds the degrees of bachelor of science from Massachusetts Institute of Technology, master of science from Wesleyan University, doctor of philosophy from George Washington University, and doctor of philosophy from Ludwig-Maximillan University (Munich). Doctor Grover commenced his teaching career as instructor in physics and astronomy at Wesleyan University and instructor in electrical engineering at Lafayette College. From 1902 to 1911 he was associated with the United States Bureau of Standards as physicist. He was professor of electrical engineering at Colby College, Waterville, Me., from 1911 to 1920. He joined the faculty of Union College in 1922 as assistant professor, becoming associate professor later that year and professor in 1932. He was a consultant to the Bureau of Standards until 1938 and is the author of several books and many technical papers. He is a member of the Institute of Radio Engineers, the American Association for the Advancement of Science, the American Physical Society, and the American Association of University Professors. He also is a member of Eta Kappa Nu.

W. G. Hoehn (A '35) formerly electrical engineer in the engineering department, American Transformer Company, Newark, N. J., has been made manager of power, distribution, and air-filled transformers. **T. W. Stauber** (A '43) formerly electrical engineer with the company, has been made manager of specialty air-insulated transformers and transtats.

M. L. Waring (A '29, M '36) formerly division engineer in system engineering, Consolidated Edison Company of New York (N. Y.), Inc., has been transferred to the service bureau. **T. C. Duncan** (A '30) formerly in purchasing and stores succeeds Mr. Waring. The transfers have been made as part of the company's executive development plan.

T. S. Sloan (A '21, M '32) vice-president, Georgia Power Company, Columbus, Ga., has been given an indefinite leave of absence because of illness and has resigned his position. Mr. Sloan has been with the company and its predecessors since 1908 and has been in Columbus since 1937.

Marie Lovett Foote (Student Member) June 1946 graduate of Duke University, has joined the AIEE editorial staff in New York, N. Y., as editorial assistant. Miss Foote was born November 29, 1926, in Brewton, Ala. She was graduated first in her class from the Murphy High School, Mobile, Ala., and received the degree of bachelor of science in electrical engineering from Duke University. For a time she was assistant in instruction in the university's civil engineering laboratory. She served as treasurer of the AIEE Student Branch at Duke University and was a member of the circulation staff of the *Duke Engineer*. She is a member of Phi Beta Kappa and was active in many college societies.

M. L. Foote

J. J. Ryan (M '23) president of the Edison Savings and Loan Association of the Consolidated Edison Company of New York, (N. Y.) Inc., has retired. Born in New York in 1881, Mr. Ryan was graduated from Columbia University in 1909 with the degree of electrical engineer. However his association with the Edison System had commenced in 1896 when he was employed in the now outmoded position of lamp boy which involved his changing the lamps on the premises of the company's customers. After graduation he was given charge of the extension and estimating department in the Bronx district of the New York Edison Company. Thereafter he was made assistant general foreman in the Bronx district in 1910, assisting operating superintendent in 1912, assistant superintendent in 1915, head draftsman in 1920, and superintendent in 1922. He was elected a director of the Savings and Loan association in 1927, vice-president in 1937, and president in 1943. He is a member of Tau Beta Pi and Sigma Xi.

Fred Clarke (A '21, M '30) merchandise manager, Western Electric Company, New York, N. Y., has retired. Mr. Clarke was graduated from Armour Institute in 1907 with the degree of bachelor of science and in 1912 received the degree of electrical engineer. Mr. Clarke's association with the Bell System commenced in 1905, at which time he was assistant traffic manager of the Chicago (Ill.) Telephone Company. After a period with the Michigan State Telephone Company, he joined the American Telephone and Telegraph Company in 1918. In 1921 he was transferred to the Ohio Bell Telephone Company as building and equipment engineer. Shortly afterwards, in 1923, he became general installation engineer for the Western Electric Company. He was appointed general sales engineer in 1927 and general merchandise manager in 1939. During World War II he served on an advisory committee of the War Production Board and in 1944 was appointed a member of its communications division committee on disposal of surplus equipment. He has served as councilman and on the town board of adjustment in Leonia, N. J.

L. B. Bender (A '20, M '27) formerly supervisor of engineering production, radio division, Westinghouse Electric Corporation, Baltimore, Md., has retired. Colonel Bender was graduated from Kansas State College in 1904 and received the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1920. He was an officer in the United States Army from 1909 until 1940 when he retired as a colonel. He was in the Coast Artillery Corps until 1917 and after that in the Signal Corps. For more than 12 years he had executive control of the research and development work of the Signal Corps as a member of the staff of the Chief Signal Officer, Washington, D. C., as director of the Signal Corps Laboratories, Fort Monmouth, N. J., and as director of the Aircraft Radio Laboratory, Wright Field, Ohio. In World War I he received the Distinguished Service Medal and during World War II was recalled to active duty as Signal Officer, Second Service Command, Governors Island, N. Y. He joined the Westinghouse corporation in 1940.

E. A. LeFever (M '34) general superintendent of meters, Buffalo (N. Y.), Niagara and Eastern Power Corporation, has retired. After his graduation from Purdue University in 1901, Mr. LeFever spent two years in the test department of the General Electric Company, Lynn, Mass. He joined the Buffalo Niagara system in 1903 as foreman of the meter department. Until 1930 he had charge of the electrical measurement work of the company. He then was given supervision of policies and methods of installing measuring devices. In 1931 he was elected chairman of the operating committee of the Niagara Hudson system. Mr. LeFever for many years was extremely active in the committee work of the National Electric Light Association and was an officer of the meter committee of the Edison Electric Institute.

F. J. Stevens (A '12, F '44) formerly vice-president in charge of engineering, American Lava Corporation, Chattanooga, Tenn., has been elected vice-president and director of D. M. Steward Manufacturing Company, Chattanooga. Mr. Stevens holds the degree of electrical engineer (1913) from Rensselaer Polytechnic Institute. After his graduation he was employed as junior railway engineer with the Public Service Commission, First District, New York, until in 1916 he joined the Locke Insulator Manufacturing Company, Baltimore, Md. In 1928 he was appointed assistant general manager of Isolantite Company of America, Inc., Belleville, N. J. He had been associated with the American Lava Corporation in various capacities since 1931 and had been vice-president since 1934. During the World War II he was loaned to the British Air Ministry as a consultant on steatite insulator production.

P. M. Gunzbourg (M '41) president, MacDonald International, Inc., New York, N. Y., and consulting engineer, has been awarded by the War Department, a Certificate of Appreciation for "patriotic services in a position of trust and responsibility" as consultant during the war to the Director of Intelligence of the Army Service Forces. At the outbreak of war in Europe, Mr. Gunzbourg served the British Government in His Majesty's Office of Works in France. Mr. Gunzbourg was born in Russia, served under the Czar's government, and worked in the electrical trust under the Soviet Government. Before the 1917 Revolution he was associated with the Russian Siemens Company and after 1926 with the Belgian and French companies. He has been in the United States since 1940.

O. J. M. Smith (A '42) formerly chief electrical engineer, Scranton (Pa.) Record Company, is now chief electrical engineer of the Summit Corporation, Scranton. Doctor Smith holds the degrees of bachelor of science in chemistry from Oklahoma Agricultural and Mechanical College (1938), bachelor of science in electrical engineering from the University of Oklahoma (1938), and doctor of philosophy from Stanford University (1941). He has been an instructor at Tufts College, Medford, Mass., assistant professor at the University of Denver, Colo., and research engineer for the Westinghouse Electric Corporation, East Pittsburgh, Pa.

F. S. Black (A '34, M '44) formerly assistant planning engineer, Potomac Electric Power Company, Washington, D. C., has been appointed assistant to the president of the company. Mr. Black received the bachelor of science degree in electrical engineering from the University of North Carolina and the bachelor of law and master of laws degrees from the National Law School. Mr. Black has been with the company since 1934. He has been instructor in evening classes at the University of Virginia. He is chairman of

the AIEE Washington Section, editor of the *Monthly Calendar* of the District of Columbia Council of Engineering and Architectural Societies, and a member of the Washington Board of Trade, the Washington Society of Engineers, and the District of Columbia's Commissioner's Committee on Veterans Housing.

M. C. Heffelman (M '45) formerly vice-president and general manager, New Mexico Power Company, Santa Fe, has been elected president of the company. He also will continue as general manager. Mr. Heffelman, who received the bachelor of science degree in 1924 and the electrical engineering degree in 1933 from the University of Arizona, early in his career was with the Phelps Dodge Corporation and with the Chile Exploration Company as supervisor of electric equipment at Chuquicamata, Chile, from 1925 to 1931. His first utility association was with the Tucson Gas Electric Light and Power Company in 1931 and 1932. He was made general manager of the Deming Ice and Electric Company in 1933, was appointed vice-president and manager in 1940, and later that year president and manager. He was elected vice-president and general manager of the New Mexico company in 1942.

S. B. Williams (A '07, F '26) switching development engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has retired from that position, but plans to open a consulting engineering office in Brooklyn, N. Y. Mr. Williams has been associated with the Bell System since he joined the Western Electric Company in Chicago, Ill., in 1905 after his graduation from Ohio State University. He was transferred to the company's circuit laboratory in New York in 1908 and to Bell Laboratories when they were organized in 1925. Since 1938 he has been concerned especially with calculating and computing device and systems, notably the development of the all-purpose computer for the Armed Forces which was constructed under his direction. He is a member of Sigma Xi and Tau Beta Pi.

P. H. McAuley (A '36, M '43) formerly staff engineer, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed vice-president of the Construction Acceptance Corporation, Pittsburgh, Pa. Mr. McAuley was graduated from Queens University in 1923 and joined the Westinghouse corporation the same year. He was in the transmission engineering department from 1924 to 1927 and after that in the engineering laboratories. In 1940 he was appointed to a liason group working on special problems.

Sidney Withington (M '20, F '24) formerly electrical engineer, New York, New Haven and Hartford Railroad Company, New Haven, Conn., has been appointed chief electrical engineer. Mr. Withington was graduated from Harvard College in 1906 and from the Harvard Engineering School in 1907. After a year as a teaching fellow at Harvard College, Cambridge, Mass., he was employed from 1908 to 1910 by the Walworth Manufacturing Company, Boston, Mass. Since 1910 he has been associated with the New York, New Haven and Hartford Railroad. Mr. Withington has written a number of technical papers and is a member of the American Society of Mechanical Engineers, the Newcomen Society, and the Railway-Locomotive Historical Society. He has served on committees of the American Standards Association.

E. C. Crittenden (A '19, F '44) assistant director, National Bureau of Standards, Washington, D. C., has been awarded the Illuminating Engineering Society Medal. The medal is given in recognition of meritorious achievement which has conspicuously furthered the profession, art, or knowledge of illuminating engineering. Mr. Crittenden has made notable contributions to the development and establishment of acceptable standards and units for the measurement of light. He is a past president of the IES, the United States National Committee of the International Commission on Illumination, the Optical Society of America, the United States National Committee of the International Electrotechnical Commission, the Washington Academy of Sciences, and the Philosophical Society of Washington.

A. L. Whitman (A' 22, M '30) lieutenant colonel, United States Signal Corps, has returned to Bell Telephone Laboratories, Inc., New York, N. Y. During his term of service in the Armed Forces, Mr. Whitman was executive officer of the Camp Evans Radar Development Laboratory and officer in charge of the Equipment Coordination Branch, the Camp Evans Signal Laboratory. In 1943 he went overseas and served on the staff of the Service of Supply Headquarters in Brisbane, Australia; as base signal officer on New Guinea; as signal officer on Luzon; and with an advance reconnaissance detachment in Manila. He later was communications officer in Manila and signal officer in Batangas.

W. A. Coates (A '14, F '26) formerly sales manager, switchgear department, Metropolitan-Vickers Electrical Company, Ltd. Manchester, England, has been appointed manager of home sales for the company. Mr. Coates attended Finsbury College and has been associated with Siemens Brothers and the British Westinghouse Company. He was chief engineer of the Canadian Electrical Company from 1912 to 1917. He has been in the employ of the Metropolitan-Vickers Company since 1919, except for the years of 1922 and 1923 which he spent in Japan and Australia for the Metropolitan-Vickers Export Company. He was appointed sales manager of the switchgear department in 1936.

S. T. Arnold (M '44) formerly distribution engineer, Boston (Mass.) Edison Company, is now with the electrical engineering department of the Army Service Forces, Manhattan District, Corps of Engineers, Oak Ridge, Tenn. Mr. Arnold was graduated from Randolph Macon College in 1926 and also holds the degrees of bachelor and master of science from Massachusetts Institute of Technology. He had been associated with the Edison company since 1931. At Oak Ridge he is concerned at present with process production and improvement at the electromagnetic isotope separation plant.

C. P. Cooper (A '08, M '21) formerly vice-president and director, American Telephone and Telegraph Company, New York, N. Y., recently became executive vice-president of the company. Mr. Cooper was graduated from Ohio State University in 1907 and the following year entered the Bell System as junior engineer for the New York Telephone Company. In 1918 he was sent to Washington, D. C., to assist in the expansion of the facilities of the Chesapeake and Potomac Telephone Company as general plant superintendent. He was appointed general manager of the Cleveland (Ohio) Telephone Company in 1920, and, when this became part of the Ohio Telephone Company, he was appointed vice-president and general manager of the new company. He has been vice-president of the American Telephone company since 1926. Mr. Cooper is president of the Presbyterian Hospital, New York; the United Hospital Fund of New York; and a director of the Guaranty Trust Company of New York.

M. M. Brandon (A '34, F '44) formerly associate electrical engineer for the Underwriters' Laboratories, has been appointed electrical engineer and as such will have full responsibility and direction of the activities of the electrical department of the laboratories in Chicago, Ill.; New York, N. Y.; and San Francisco, Calif. His headquarters will be in New York. Mr. Brandon holds the degrees of bachelor of science (1919) and electrical engineer (1936) from Mississippi State College. He joined the Underwriters' Laboratories in 1921 in Chicago. He has been active in the affairs of the International Association of Electrical Inspectors and of the electrical committee of the National Fire Protection Association.

A. J. Devereaux (A '37) formerly electrical engineer, J. F. Pritchard and Company, Kansas City, Mo., has been appointed electrical engineer in charge of the elec-

trical engineering department of the Otter Tail Power Company, Fergus Falls, Minn. Mr. Devereaux was graduated from Iowa State College in 1922. He was associated with the General Electric Company, Schenectady, N. Y., in the testing, construction, and switchgear departments from 1922 to 1935. In 1935 he became assistant electrical engineer for the Central Nebraska Public Power and Irrigation District and later was electrical engineer in charge of design for the Continental Oil Company, Ponca City, Okla. He joined the J. F. Pritchard company in 1942.

J. G. Tarboux (A '21, F '43) formerly head of the department of electrical engineering, University of Tennessee, Knoxville, has been appointed professor of electrical engineering at Cornell University, Ithaca, N. Y. Professor Tarboux was graduated from Clemson Agricultural College in 1918 and from Cornell University received the degrees of electrical engineer in 1923, master of electrical engineering in 1926, and doctor of philosophy in 1937. He was made instructor in electrical engineering at Cornell University in 1920 and assistant professor in 1926. He joined the University of Tennessee faculty in 1929. He is the author of several books and a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

David Sarnoff (M '23) president of the Radio Corporation of America, New York, N. Y., recently awarded the Medal for Merit, was commended because he "placed the full resources of his company at the disposal of the Army whenever needed, regardless of the additional burden imposed upon his organization. He encouraged key personnel to enter the service, and at his direction, RCA engineers and technicians rendered special assistance on numerous complex communications problems. He fostered electronic advances which were adapted to military needs with highly beneficial results." Mr. Sarnoff previously was awarded the Legion of Merit medal in 1944 for his services overseas as brigadier general.

T. M. Odarenko (M '42) products line manager, Federal Telephone and Radio Corporation, Clifton, N. J., who during the war was technical director of the radio frequency transmission lines and fitting section of the electronics division of the Bureau of Ships, has been presented with the Distinguished Civilian Service Award for "outstanding service to the United States Navy in the field of electronics during World War II." Among the contributions mentioned in the citation were "the development and production of the new cable dielectric Polyethylene. . . a unified joint Army–Navy inspection procedure. . . standardization of the Army–Navy use of approximately 40 cable types in contrast to the 200 odd types which were in current use. . . formation of the War Committee on Dielectrics."

C. O. Bickelhaupt (M '22, F '42) vice-president and secretary, American Telephone and Telegraph Company, New York, N. Y., and brigadier general in the United States Signal Corps during World War II recently received the Distinguished Service Medal in recognition of his service as director of the communications division and director general of the Signal Communications Service in the European theater of operations from December 1944 to July 1945. Mr. Bickelhaupt, who had been in military service in World War I, was recalled to active duty in 1941. He was assigned to the Office of the Chief Signal Officer in Washington, D. C., and was liaison officer, assistant director of planning, chief of the executive control branch, director of the control division, and assistant executive. Before going overseas in 1944 he was commanding officer of the replacement training center at Fort Monmouth, N. J.

D. D. Smalley (A '20, M '33) formerly superintendent, central area, operation department, Pacific Gas and Electric Company, San Francisco, Calif., has been named engineer of electric operation. Shortly after his graduation from the University of California in 1910, Mr. Smalley joined the Merced River Company which later merged with the San Joaquin Light and Power Corporation. In 1934 he became general superintendent of the San Joaquin and Midland County systems and in 1944 was appointed superintendent of the central area, **G. H. Hagar** (A '20, M '26) formerly assistant engineer in the operations department succeeds Mr. Smalley as superintendent of the central area. Also a graduate of the University of California, Mr. Hagar has been with the company since 1913.

Harris Reinhardt (M '42) formerly quality supervisor, appliance department, Sylvania Electric Products, Inc., Ipswich, Mass., has been appointed manager of the commercial engineering department of the company's lighting division. Mr. Reinhardt, who holds the degrees of bachelor of science from the University of Arkansas and master of science from Ohio State University, has been with the company since 1940. Previously he was associated with the Westinghouse Lamp Division, Bloomfield, N. J.

G. A. Waters (A '07, F '21) formerly chief engineer, electric division, engineering department, Wagner Electric Corporation, St. Louis, Mo., has been appointed vice-president in charge of manufacturing. In 1907, after his graduation from Syracuse University, Mr. Waters became an instructor at Washington University, St. Louis. He joined the Wagner Corporation in 1909 as student engineer. Mr. Waters recently received a citation from the United States Army for his liaison work with the Ordnance Division during the war. He is a past president of the St. Louis Electrical Board of Trade and the St. Louis Engineers' Club and a member of the Society of Automotive Engineers.

A. M. MacCutcheon (A '12, F '26) senior vice-president, Reliance Electric and Engineering Company, Cleveland, Ohio, and AIEE past president (1936–37), has retired. However, he will remain available to the company as a consultant. Mr. MacCutcheon, a graduate of Columbia University, joined the Reliance company in 1914 to design a new line of adjustable speed d-c motors. He became chief engineer in 1917, and engineering vice-president in 1923 and has continued as an officer of the company since that time. Mr. MacCutcheon has been active in the development of the Cleveland Technical Societies Council and has been chairman of the city's Water Action Committee.

F. R. George (A '13, M '25) engineer of electric operation, Pacific Gas and Electric Company, San Francisco, Calif., has retired. Mr. George was graduated from the University of Southern California in 1901 and shortly afterwards was associated with the Mutual Electric Light Company, San Francisco and the Bay Counties Power Company, Oakland, Calif., both predecessors of the Pacific Gas and Electric Company. When the latter company was incorporated in 1905 he remained as engineer at Oakland. He became chief load dispatcher in 1910 and was transferred to San Francisco in 1908. In 1921 he was made engineer of electric operation. He is a member of the Pacific Coast Electric Association.

F. V. Smith (A '23, M '38) a partner and assistant chief electrical engineer, Sargent and Lundy, Engineers, Chicago, Ill., has been appointed chief electrical engineer of the firm. Mr. Smith was born in 1900 in Victoria, Australia, and holds the degrees of bachelor and master of science from the University of Melbourne. He was with the Westinghouse Electric and Manufacturing Company from 1922 to 1927. In 1927 he joined the staff of Sargent and Lundy and in 1945 became a partner and assistant chief electrical engineer. Mr. Smith has been chairman of the AIEE Chicago Section and has served on a number of AIEE committees.

F. H. Hollister (A '08, F '43) partner and chief electrical engineer, Sargent and Lundy, Engineers, Chicago, Ill., has retired. After his graduation from the University of Michigan in 1906, Mr. Hollister

was associated with the General Electric Company in Schenectady, N. Y., and Atlanta, Ga., until 1916. In that year he joined the staff of Sargent and Lundy and in 1930 became chief electrical engineer. He has served on a number of AIEE committees and was chairman of the power generation committee in 1935–36. He is a member of the Western Society of Engineers.

John Van Veen (A '20, M '28) formerly superintendent, electric operating department, Cincinnati (Ohio) Gas and Electric Company, has been appointed assistant manager of the electric department. Mr. Van Veen joined the company in 1913 soon after coming to the United States from Holland. **S. M. Hamill, Jr.** (A '28, M '36), formerly assistant superintendent, electric operating department, succeeds Mr. Van Veen as superintendent. He has been with the company since 1923.

Sydney Alling (A '12) formerly engineer in the industrial department, Rochester (N. Y.) Gas and Electric Corporation, has been named manager of the department. Mr. Alling was graduated from the University of Rochester and received the degree of electrical engineer from the Massachusetts Institute of Technology. He entered the employ of the Rochester company in 1911 and has been in the industrial department since 1931.

H. E. Edwards (A '41) formerly design engineer, Westinghouse Electric Corporation, Mansfield, Ohio, has been made section engineer in charge of laundry equipment engineering. Mr. Edwards, who joined the corporation in 1932, previously was associated with the Columbia Steel Company, Elyria, Ohio, and the National Tube Company, Lorain, Ohio.

C. D. Kester (A '13) formerly manager, machinery electrification section, industrial department, Westinghouse Electric Corporation, Philadelphia, Pa., has been appointed manager of the York, Pa., office of the corporation. A graduate of Lehigh University, Mr. Kester joined the Westinghouse corporation in 1912 and has been manager of the materials handling machinery section and of the synchronous motor section.

J. A. Wood, Jr. (A '30) formerly assistant professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, has been appointed to the faculty of the Thayer School, Dartmouth College, Hanover, N. H., as assistant professor of electrical engineering. He will supervise the installation of new electrical laboratory equipment and will direct the electronics work in the school's new electrical engineering course.

U. R. Furst (A '44) formerly chief electronic engineer, engineering department, Russell Electric Company, Chicago, Ill., recently formed his own company, Furst Electronics, Chicago. Mr. Furst received the degrees of master of science in 1935 and doctor of philosophy in 1938 from the University of Vienna. He is a member of the Institute of Radio Engineers.

E. W. Grover (M '29) superintendent of substations, Commonwealth Edison Company, Chicago, Ill., has retired. Mr. Grover was graduated from Armour Institute of Technology in 1904. He was employed first by the company on a construction project in 1904, later that year entering the substation department as operator, in 1906 becoming district operator. He was appointed assistant superintendent of substations in 1910 and superintendent of substations in 1935.

F. J. Gallogly (A '41) formerly assistant electrical engineer, field production department, United States Navy Yard, Brooklyn, N. Y., has joined the staff of the American Standards Association, New York, N. Y. Mr. Gallogly was graduated from Manhattan College in 1940 and before joining the Navy Department in 1941 was employed by the Ingersoll-Rand Company.

W. B. Creagmile (A '07) formerly technical engineer, J. G. Biddle Company, Philadelphia, Pa., has retired. Mr. Creagmile was graduated from Drexel Institute in 1896. After 20 years on the faculty of Drexel Institute, he joined the Biddle Company in 1919. He has been technical engineer and engineering adviser to Mr. Biddle and to the sales and manufacturing staffs of the company, and is the author of many of the company's publications.

A. A. Browne (A '38) formerly manager, sales and engineering, Joshua Hendy Iron Works, Sunnyvale, Calif., has been appointed general manager of the Pacific Electric Manufacturing Corporation, San Francisco, Calif. Mr. Browne, a 1930 graduate of the University of Washington, was associated with the Westinghouse Electric Corporation, San Francisco, from 1930 to 1941. In 1942 he became assistant to the president of the Joshua Hendy works.

F. B. Jewett (A '03, HM '45) retired vice-president of the American Telephone and Telegraph Company, New York, N. Y., has received the Medal of Merit for "outstanding services as president of the National Academy of Sciences and as member of the National Defense Research Committee.

D. F. Tuttle, Jr. (A '38) who recently returned to Bell Telephone Laboratories, Inc., after serving as a naval lieutenant in the Pacific, has received a Gerard Swope Fellowship. The fellowships are awarded annually by the General Electric Company to electrical engineering graduates who have demonstrated outstanding abilities in the field of engineering and research. Mr. Tuttle is studying for his doctorate at Massachusetts Institute of Technology.

R. E. Roesch (A '25, M '33) formerly colonel in the United States Signal Corps, is now with the International General Electric Company, Schenectady, N. Y. Mr. Roesch served with the Signal Corps from 1941 to 1946 with the major portion of his service in the Far East. Before the war he was with Stone and Webster Engineering Corporation.

B. L. Kilgour (M '38) formerly vice-president, Cincinnati (Ohio) and Suburban Bell Telephone Company, has been elected president of the company. Mr. Kilgour was graduated from Harvard University in 1927 and commenced work with the American Telephone and Telegraph Company, New York, N. Y. He was transferred to the Cincinnati company in 1930, becoming assistant to the president and then vice-president. He is a member of the Newcomen Society and the Caledonian Society and a director of the Central Trust Company and the Street Railway Company, both of Cincinnati.

P. L. Adkins (A '37) formerly engineer with the United States Engineers, Portland, Oreg., has been sent to Formosa and Northern China with a party of engineers which is making a rehabilitation survey of transmission and distribution facilities for the J. G. White Engineering Corporation, New York, N. Y. A graduate of Oregon State College, Mr. Adkins has had 20 years experience with power companies on the Pacific Coast, and worked on Rural Electrification Administration projects in Washington, Idaho, and Oregon. He joined the United States Engineers in 1942.

Clinton Rector (A '27) formerly general sales manager, Catalin Corporation, New York, N. Y., has been appointed vice-president of National Engineering Products, Inc., Washington, D. C. Mr. Rector was graduated from Johns Hopkins University in 1924, and for four years thereafter was employed by the Westinghouse Electric Corporation, Pittsburgh, Pa. From 1928 to 1944 he was sales engineer for the Bakelite Corporation, New York, N. Y. In 1944 he was made sales manager for the Catalin Corporation. He is member of Tau Beta Pi.

J. N. Mochon (A '45) chief examiner, Quebec Board of Electrical Examiners, Montreal, Canada, has retired from that position. He was named to the board which he organized first in 1919, at which time he was acting as assistant superintendent of lighting for the City of Montreal. Before 1914 he was connected with the sales organization of Allis-Chalmers-Bullock, Ltd., Montreal, and was a partner in the Quebec agents of the Swedish General Electric Company.

D. L. Solomon (A '40, M '43) formerly project engineer, telephone engineering department, Federal Telephone and Radio Corporation, Newark, N. J., has been ap-

pointed assistant chief telephone engineer, Stromberg-Carlson Company, Rochester, N. Y. Mr. Solomon, a 1936 graduate of Purdue University, has been transmission engineer with the Western Union Telegraph Company, Chicago, Ill., and consulting telephone engineer with the estate of H. M. Friendly, Chicago. He is a member of the communications section of the Association of American Railroads.

J. E. Hunt (A '43) formerly superintendent of generating stations, Philadelphia (Pa.) Electric Company, has been appointed administrative engineer of electric operations. Associated with the company since 1904, Mr. Hunt has been superintendent of its Schuykill Station from 1917 to 1925 and superintendent of its Richmond Station from 1925 to 1939. In the latter year he became superintendent of generating stations.

M. M. Kenneally (M '29) of the sales and engineering department, Joslyn Manufacturing and Supply Company, Chicago, Ill., has been made sales manager for the company. A graduate of Iowa State College, Mr. Kenneally formerly was associated with the United Gas Improvement Company, Philadelphia, Pa.; the Ohio Brass Company, New York, N. Y.; and the Porcelain Insulator Corporation, Lima, N. Y. He entered the employ of the Joslyn company in 1944.

R. T. Strong (A '39) formerly captain, United States Navy, has rejoined the Westinghouse Electric Corporation as manager of its San Diego, Calif., office. Called to active duty in 1941, Captain Strong served as supervising beachmaster in the assaults on Attu, Kiska, Kwajalein, Guam, and Leyte. He received the Legion of Merit Medal and the Bronze Star.

H. N. Misenheimer (M '37) formerly lieutenant colonel, United States Army, has returned to Bell Telephone Laboratories, Inc., New York, N. Y. Colonel Misenheimer served with the Signal Corps at Mitchel Field, N. Y., Fort Monmouth, N. J., with the Office of Strategic Services in Washington, D. C., and in Australia and New Guinea. For meritorious service as signal officer for all of New Guinea he was awarded the Bronze Star Medal.

W. G. Hall (A '38 M '45) formerly manager of the renewal parts department, Reliance Electric and Engineering Company, Cleveland, Ohio, has been made manager of a combined renewal parts and service division for the company. Mr. Hall, a 1934 graduate of the Case School of Applied Science, also received the degree of electrical engineer from that institution in 1943. He has been with the Reliance company since 1937.

R. E. Armington (A '42) formerly with the electrical engineering design department, Westinghouse Electric Corporation, Sharon, Pa., has joined the staff of the Ordnance Research Laboratory of Pennsylvania State College, State College, as assistant professor of engineering research. Professor Armington received his bachelor of science degree from Tufts College in 1940 and his master of science degree from New York University in 1941, and in the latter year entered the employ of the Westinghouse corporation.

G. A. Sawin (A '03, M '13) director of the regulatory legislation department, National Electrical Manufacturers Association, New York, N. Y., has retired. Mr. Sawin was associated early in his career with the General Electric Company, Lynn, Mass., and with the Public Service Electric and Gas Company, Newark, N. J. From 1920 to 1939 he was with the Westinghouse Electric Corporation, East Pittsburgh, Pa. He joined the National Electrical Manufacturers Association in 1939.

F. M. Farmer (A '07, F '13) vice-president and consulting engineer, Electrical Testing Laboratories, Inc., New York, N. Y., and past president of AIEE, recently was awarded a certificate of "Commendation for Meritorious Civilian Service" by the War Department for "outstanding performance of duty" as technical consultant, New York Ordnance District, from March 1942 to April 1945.

W. C. Cauthen (M '36) formerly colonel, Ordnance Department, Army of the United States, has joined C. F. Braum and Company, Alhambra, Calif. Mr. Cauthen, who entered the service as captain in 1940, served in Australia, New Guinea, and the Philippines and holds the Legion of Merit award and the Bronze Star Medal. He is a 1924 graduate of the University of California.

E. L. Moreland (A '11, F '21) has relinquished his position as dean of the school of engineering, Massachusetts Institute of Technology, Cambridge, Mass., to resume active partnership in the firm of Jackson and Moreland, Boston, Mass., from which he has been on leave of absence during the war years. Mr. Moreland will continue at the institute on a part-time basis as executive vice-president.

J. B. Trevor (A '34) who served as civilian engineer on the staff of the Naval Research Laboratory, Anacostia, D. C., during the war, has been presented with the Navy's Meritorious Civilian Service Award "for devising methods required to analyze X-ray radiations from radar equipment, so that means could be provided for preventing injury to operating personnel."

C. G. Suits (M '41) vice-president and director of the research laboratory, and **H. A. Winne** (A '16, F '45) vice-president in charge of engineering policy, General Electric Company, Schenectady, N. Y., and **Zay Jeffries** (M '36, F '42) vice-president and general manager of the company's chemical department at Pittsfield, Mass., have been appointed as an advisory committee on the research program in atomic energy which the company will undertake at Hanford, Wash.

C. J. Hejda (M '36, F '44) formerly chief testing engineer, Commonwealth Edison Company, Chicago, Ill., has retired. Mr. Hejda commenced his career with the company in 1903 as a draftsman. He then became an apprentice substation operator and in 1924 was appointed senior testing engineer. He was advanced to chief testing engineer in 1936.

H. V. Rathbun (A '29, M '37) formerly lieutenant colonel in the United States Signal Corps, has returned to his position with the Copperweld Steel Company and will reside in Kansas City, Mo. Mr. Rathbun first joined the company in 1941. In the Army he was commander of a signal battalion which installed communication equipment for the Army Air Forces in India.

W. R. Graham (A '38) formerly lieutenant, United States Naval Reserve, has resumed his duties as New York district manager for the Ohio Brass Company. Mr. Graham previously held this position from 1938 until he was called to active duty in 1943.

H. F. Brown (A '23, M '25) formerly assistant electrical engineer, New York, New Haven and Hartford Railroad Company, New Haven, Conn., has been appointed engineer of electric traction. Mr. Brown was graduated from Yale University in 1907 and has been with the railroad since 1910.

W. L. Whyte (A '35) formerly electrical engineer, Public Works Department, the Uganda Protectorate Government, Kampala, has received a promotion in the Colonial Civil Service and is now engineer of the Electrical Department in Malaya.

O. W. Eshbach (A '17, F '37) dean, Northwestern Technological Institute, Evanston, Ill., has been awarded the Octave Chanute Medal for 1945 by the Western Society of Engineers. The medal, founded in 1901, is awarded annually for the best paper on some aspect of engineering education.

N. J. Roberts (A '44) formerly division industrial engineer, Ohio Public Service Company, Cleveland, has been appointed chief industrial engineer for the company. Mr. Roberts joined the company in 1923 as industrial engineer a year after his graduation from Purdue University.

Charles Friedman (A '45) formerly lieutenant, junior grade, United States Navy, has been appointed assistant sales manager

of the Radio Receptor Company, New York, N. Y. A graduate of Massachusetts Institute of Technology, Mr. Friedman was a civilian engineer with the United States Army Signal Corps before he joined the Navy.

A. F. Morairty (A '43) formerly vice-president and assistant general manager, Central Arizona Light and Power Company, Phoenix, has resigned from those positions but will continue as special assistant to the president. Mr. Morairty joined the company 20 years ago as sales manager.

M. S. Barnes (A '18, M '31) formerly sales engineer, central station department, General Electric Company, San Francisco, Calif., has been made assistant manager of the central station division of the company. Mr. Barnes joined the company in Schenectady, N. Y., in 1914 after his graduation from the University of California.

H. B. Sargent (M '40) formerly vice-president and general manager, Mississippi Power and Light Company, Jackson, has resigned to become executive vice-president of the Central Arizona Light and Power Company, Phoenix. A graduate of Tulane University, Mr. Sargent had been with the Mississippi company since 1927.

E. W. Jackson (A '46) refinery electrician, Bahrein Petroleum Company, Ltd., Bahrein Island, Persian Gulf, claims the distinction of being the only member of any technical or professional society in the Persian Gulf area.

C. A. Powel (M '20, F '41) manager, headquarters engineering departments, Westinghouse Electric Corporation, East Pittsburgh, Pa., who recently served as chief of the electrical and radio branch of the Allied Control Commission in Germany has returned to the United States.

H. C. Rankin (A '29, M '34) formerly laboratory engineer of the New England Power Service Company, Providence, R. I., has been transferred to the power sales department of the Narragansett Electric Company, Providence. Mr. Rankin is a specialist in meter engineering.

J. W. Doolittle (A '26, M '33) personnel supervisor, executive department, Southern California Telephone Company, Los Angeles, has been appointed general accounting employment supervisor.

J. B. Hedley (A '34) apparatus engineer Canadian General Electric Company, Ltd., has been transferred from the Vancouver to the Victoria, British Columbia, office of the company.

W. O. Kyte (A '33) formerly lieutenant, Signal Corps, United States Army, has been made manager of the advertising and sales promotion division of the General Electric Company office in Los Angeles, Calif. Mr. Kyte was radar officer with the 9th Bombardment Division overseas.

K. E. Gould (A '36) of the transmission development department, Bell Telephone Laboratories, Inc., New York, N. Y., has been assigned to the Civil Communications Section in Tokyo, Japan, to help direct the rehabilitation of the country's war-damaged communication facilities.

E. L. Bowles (A '22, F '33) formerly professor, Massachusetts Institute of Technology, Cambridge, and special assistant to the Secretary of War, has been appointed consultant on research and development to the Automatic Electric Company.

P. H. Thayer (A '39) formerly lieutenant, United States Navy, assigned to the electronic field service group, Naval Research Laboratory, Washington, D. C., has returned to Bell Telephone Laboratories, Inc., New York, N. Y.

R. C. Disque (M '20) dean of the college of engineering and dean of the faculty of Drexel Institute of Technology, Philadelphia, Pa., recently received the honorary degree of doctor of engineering from Stevens Institute of Technology.

M. J. Kelly (M '26, F '31) executive vice-president, Bell Telephone Laboratories Inc., New York, N. Y., recently was awarded the honorary degree of doctor of science by the University of Kentucky.

J. H. Vivian (A '34, M '40) formerly protection engineer, Southern California Edison Company, Los Angeles, has been appointed electrical and maintenance engineer for the company.

W. V. Woodward (A '46) formerly power sales supervisor, Northern Indiana Public Service Company, Hammond, has become sales and application engineer with N. M. Mintz, Chicago, Ill.

L. E. Garlinghouse (A '37) formerly superintendent of the Swan Falls Power Plant, Idaho Power Company, Kuna, has been made superintendent at American Falls.

P. A. Duchastel (A '45) formerly with Ferranti Electric Ltd., Montreal, Quebec, Canada, has joined the engineering department of the Quebec Power Company, Montreal. Mr. Duchastel was graduated from McGill University in 1938.

R. W. Vonasch (A '35, M '44) formerly application engineer, federal and marine department, Ward Leonard Electric Company, Mount Vernon, N. Y., has been appointed manager of the company's newly established Newark, N. J., branch.

H. C. Lindberg (A '35) formerly of the engineering department of the Buffalo, N. Y., office of the General Electric Company, has been appointed engineer of the office.

J. T. Littleton (A '23, F '28) formerly associate director of research, Corning (N. Y.) Glass Works, has been appointed director of research. Doctor Littleton is also a vice-president of the company.

E. B. Love (A '41) formerly electrical test engineer, Consolidated-Vultee Aircraft Corporation, San Diego, Calif., has joined the California Electric Works, San Diego.

E. H. Jacobs (F '17) manufacturers' representative of Dallas, Tex., has been appointed Texas representative of the Electrical Engineers Equipment Company.

E. J. Poitras (A '33) formerly section chief, Office of Scientific Research and Development, Washington, D. C., has been elected director of engineering of Fenwal, Inc., Ashland, Mass.

E. C. Starr (M '29, F '41) professor of electrical engineering, Oregon State College, Corvallis, was selected by the National Academy of Sciences to be one of the 20 civilian scientists observing the July atomic bomb tests at Bikini atoll.

E. W. Fortune (A '41) formerly district superintendent, engineering department, Virginia Electric and Power Company, Clifton Forge, has been appointed manager of the company's Roanoke, Va., district.

W. K. Lewellen (A '37) formerly chief, contract and electrical section, First Service Command, Boston, Mass., has been appointed power sales engineer for the Lowell (Mass.) Electric Light Corporation.

J. M. Weir (A '28) formerly superintendent, Public Utility District 1, Cowlitz County, Longview, Wash. has become manager of the public utilities in Ketchikan, Alaska.

O. P. Cleaver (A '36) formerly major with the Army Engineer Board, Fort Belvoir, Va., recently was made a lieutenent colonel and director of Division II of the Board.

Scott Beamer (A '37) formerly first lieutenant in the United States Army, now is associated with Clyde Bently, San Francisco, Calif.

H. T. Bryans (A '43) formerly superindentent, Barbadoes station, Philadelphia Electric Company, Norristown, Pa., has been appointed superintendent of the company's Delaware station.

W. V. Kahler (M '39) general manager, Illinois Bell Telephone Company, Chicago, Ill., has been elected vice-president of the Western Society of Engineers.

E. W. Conway (A '30, M '44) district plant manager, Chesapeake and Potomac Telephone Company, Washington, D. C., has been appointed general plant supervisor.

O. Howarth (A '24, M '33) technical engineer, superintendent of the testing department, Lancashire Electric Power Company, Manchester, England, has been appointed sales manager and technical adviser to control all selling activities of the company.

G. R. Henninger (A '22, F '43) AIEE editor, New York, N. Y., recently was elected a director of the New York County chapter of the National Society of Professional Engineers for the 1946–48 term.

Rufus Moses (A '28, M '42) Youngstown division manager of the Ohio Edison Company, has been elected a vice-president of the company. Mr. Moses is also a director of the company.

E. H. Thompson (A '45) formerly district plant manager, Southern Bell Telephone and Telegraph Company, New Orleans, La., has been appointed Louisiana plant superintendent.

H. B. Bryans (M '17, F '18) executive vice-president, Philadelphia (Pa.) Electric Company, has been elected to the board of managers of the Western Saving Fund Society of Philadelphia.

C. F. Publow (A '17, M '26) district station engineer, Hydro-Electric Power Commission of Ontario, Toronto, Canada, has been elected president of the Royal Canadian Institute.

C. D. Coy (A '31) buildings superintendent, Cincinnati (Ohio) and Suburban Bell Telephone Company, has been appointed plant supervisor.

OBITUARY • • • •

Severn D. Sprong (A '03, M '09, F '12) consulting engineer, New York, N. Y., died June 27, 1946. Mr. Sprong was born in East Greenbush, N. Y. He completed the test course of the General Electric Company, Schenectady, N. Y., in 1893 and became superintendent of the electric department of the Consolidated Gas Company of New Jersey, Long Branch, in 1898. He was chief engineer of the Central Electric Company in New Jersey in 1900, assistant chief electrical engineer of the New York (N. Y.) Edison Company in 1902, assistant electrical engineer of the United Electric Light and Power Company in 1906, and chief electrical engineer of the Brooklyn Edison Company in 1912. From 1909 to 1912 he was chief electrical and mechanical engineer for J. G. White and Company, New York. He was officer in a number of utility companies from 1922 to 1925, the Orange County Public Service Corporation, the Orange County Hydro-Electric Corporation, the Pike County Light and Power Company, the Cape May Illuminating Company, and the Port Jervis Traction Company. He had maintained consulting offices since 1922. Mr. Sprong was an AIEE vice-president from 1912 to 1914 and a manager from 1909 to 1912. He was a member of the Society of Colonial Wars, the Sons of the Revolution, the Holland Society of New York, the St. Nicholas Society, the Engineers Club, the American Society of Mechanical Engineers, and the Edison Pioneers.

John Barclay Fisken (A '03, M '13, F '13) retired consulting engineer for the Washington Water Power Company, Spokane, and pioneer in the electrical utility industry in the Northwest, died recently. Mr. Fisken was an AIEE vice-president for 1919–1920 and a manager from 1916 to 1919. He was born in Helensburgh, Dumburtonshire, Scotland, November 2, 1861, and was graduated with First Class Honors from the City and Guilds of London Institute in 1882. His first position in the United States was superintendent for the Seattle (Wash.) Gas Company in 1886, and the following year he was manager of the Victoria (British Columbia, Canada) Electric Illuminating Company, Ltd. In 1887 he moved to Spokane Falls, Washington Territory (now Spokane, Wash.), and from 1887 to 1896 he was superintendent for the predecessors of the Washington Water Power Company—the Spokane Falls Electric Light and Power Company and the Edison Electric Illuminating Company. He was consultant for the company's first high-voltage line built between Spokane and the Coeur d'Alene mines. He was appointed chief engineer in 1918 and consulting engineer in 1920. For a number of years also he supervised the company's safety program. Mr. Fisken was a member of the Northwest Scientific Association and the Associated Engineers of Spokane.

Robert Blanchard Shepard (A '25, M, 26, F '36) chief electrical engineer, Underwriters' Laboratories, Inc., New York, N. Y., died June 20, 1946. Born in Hudson, N. Y., November 13, 1888, Mr. Shepard was graduated from Union College with the degree of bachelor of engineering in 1910. After a brief period in the switchboard department of the General Electric Company, Schenectady, N. Y., he became an inspector for the Underwriters' Association of New York State in Schenectady in 1912. He was named resident engineer in the Underwriters' Laboratories in 1913 and was transferred to New York as assistant electrical engineer in 1917. In 1922 he was titled associate electrical engineer and in 1924 was appointed chief electrical engineer. His work included contact with various technical societies, and he was a member and active committee member of the American Society for Testing Materials, the International Association of Electrical Inspectors, and the National Fire Protection Association. He served as well on many of the sectional committees of the American Standards Association.

Harry Foster Shearer (M '45) engineer in charge of test, Burlec division, Canadian Line Materials, Toronto, Ontario, died May 24, 1946. Mr. Shearer was born May 16, 1885, in Simcoe, Ontario, and was graduated from the University of Toronto with the degree of bachelor of science in 1909. From 1909 to 1913 he was associated as test engineer with the Allis-Chalmers Manufacturing Company, Cincinnati, Ohio; as design engineer with Smith, Keary, and Chace, Toronto; and as sales engineer with the Moloney Electric Company, Windsor, Ontario. He joined the staff of the Toronto Hydro-Electric System as power engineer in 1913 and became manager at Smith's Falls, Ontario, in 1917 and at Welland, Ontario, in 1922. He was made sales engineer for the Canfield Electric Works, Toronto, in 1938 and inspector for the Canbridge Company, Ojibway, Ontario, in 1941. He entered the employ of the Canadian Line Materials in 1943.

William Corwin Burton (A '93, M '99) retired member of J. G. White and Company, New York, N. Y., died April 18, 1946, in Pasadena, Calif. Mr. Burton, who was born April 24, 1872, in Saginaw, Mich., received the degrees of bachelor of science in 1893 and electrical engineer in 1899 from the University of Wisconsin. In 1894 he joined the J. G. White organization. Mr. Burton was concerned particularly with the construction of railroads, street railway, and subway systems, in the United States as well as in Australia, New Zealand, India, Japan, and England. He was sent to London, England, in 1900, and there became director of J. G. White and Company, Ltd. He returned to New York in 1919 and until his retirement in 1934 represented British enterprises. He was president of Connett, Burton and Company from 1919 to 1928 and of the Booth American Shipping Company from 1926 to 1934.

William Requa Van Bokkelen (A '12, M '26) consulting engineer, Berkeley, Calif., died May 22, 1946. Born September 25, 1884, in Oakland, Calif., Mr. Van Bokkelen was graduated from the University of California with the degree of bachelor of science in 1906. His first position was that of draftsman and office assistant for Henry R. Worthington, San Francisco, Calif., in 1906. He was an electrician's

helper with the Pacific Gas and Electric Company, San Francisco, in 1910, and in 1911 joined the Coast Counties Gas and Electric Company as assistant to the general manager. He was electrical engineer of engineering and operation from 1916 to 1919 and in 1919 was made chief engineer.

Thomas Loren Cooke, Jr. (A '41) illumination engineer, Toronto, Ontario, Canada, died May 27, 1946. Mr. Cooke was born in Rochester, N. Y., October 23, 1916, and received the bachelor of science degree from the University of Toronto in 1938 and the master of science degree from the University of Michigan in 1940. He was employed in the lighting service section of the Hydro-Electric Power Commission of Ontario, Toronto, in 1938 and 1939. From 1940 to 1945 he was a member of the equipment department of the Austin Company, Cleveland, Ohio, and worked on projects in Los Angeles, Calif., and New York, N. Y., as well as in Cleveland. During the past year he was in charge of electrical work in the building of a Navy training ship at Newport, R. I.

Philip Goldstone (M '24) engineer, Gibbs and Hill, Inc., New York, N. Y., died April 29, 1946. Mr. Goldstone, who was born February 21, 1885 in Russia, was graduated from Cooper Union in 1909 and in 1912 received the degree of civil engineer from Brooklyn Polytechnic Institute. Before joining Gibbs and Hill in 1914, he was draftsman with Viele, Blackwell, and Buck, New York. In the ensuing years most of Mr. Goldstone's work lay in the field of railroad electrification. His work progressively covered, catenary design, economic studies, and power distribution. His efforts were instrumental in obtaining for the Pennsylvania Railroad one of the first a-c calculating boards offered for sale by the manufacturer, and its operation since had been under his direction.

Shaw Hooks Hardy (A '46) manufacturers' agent, Miami, Fla., died May 26, 1946. Born November 24, 1894, in Monticello, Ga., Mr. Hardy was graduated from the Georgia School of Technology in 1917 with the degree of bachelor of science. After serving in the United States Navy, he became salesman and lighting specialist for the General Electric Company, Atlanta, Ga., from 1919 to 1925. He was also engineer for the Okonite Cable Company, Birmingham, Ala., from 1925 to 1932 and for the General Electric Supply Corporation from 1932 to 1936. In 1936 he became a manufacturers' agent, first in association with Pat Baldwin, Inc., and after 1942, independently. He was a member of the Florida Engineers Society.

Kenneth Oscar Houser (A '44) power consultant, industrial sales department, Kansas Gas and Electric Company, Wichita, died April 16, 1946. Mr. Houser, who was born in Crystal Springs, Kan., October 26, 1898, was graduated from Kansas State College in 1922 with the degree of bachelor of science. He completed the test course of the General Electric Company, Fort Wayne, Ind., in 1924 and was transferred to transformer sales in Pittsfield, Mass. He became transformer specialist engineer for the Kansas City Power and Light Company, Kansas City, Mo., in 1925 and industrial engineer for the Kansas Gas and Electric Company in 1926. He was named power consultant in 1944.

Otto Weiss (M '46) advisory engineer, Charles M. Terry Ltd., Sydney, New South Wales, Australia, died March 28, 1946. Mr. Weiss was born March 8, 1898, in Vienna, Austria, and was graduated from the Vienna Technical University in 1922. After a two-year period with the Austro-Hungarian Electric Welding Machine Company of Vienna, he entered the employ of the Elin Electric Manufacturing Company, Ltd., Vienna. With that company from 1924 to 1938, he was designing engineer, engineer in charge of the welding department, and finally chief engineer. After the Nazis occupation in 1938, Mr. Weiss went to Australia and joined the Terry company.

Henry Martin Killingsworth (A '45) manager, General Electric Company, Miami, Fla., died June 4, 1946. Mr. Killingsworth, who was born January 21, 1907, in Snellings, S. C., was graduated from Clemson Agricultural and Mechanical College in 1929 with the degree of bachelor of science. Mr. Killingsworth was with the General Electric Company in Philadelphia, Pa., from 1929 to 1936 in the test course and in commercial engineering and sales work. He was switchgear specialist in Atlanta, Ga., from 1936 to 1942 and in the latter year was transferred to Miami.

MEMBERSHIP . . .

Recommended for Transfer

The board of examiners, at its meeting of July 18, 1946, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the secretary of the Institute.

To Grade of Fellow

Berry, J. H., dist. mgr., elec. dept., Virginia Elec. & Pr. Co., Norfolk, Va.

Crowdes, G. J., asst. chief elec. engr., Simplex Wire & Cable Co., Cambridge, Mass.

Crymble, A. C., special projects engr., Tennessee Eastman Corp., Kingsport, Tenn.

Edgerton, H. E., assoc. prof. of elec. engg., Massachusetts Inst. of Tech., Cambridge, Mass.

Kahler, W. V., genl. mgr., Illinois Bell Tel. Co., Chicago, Ill.

Kistler, R. E., trans. & protection engr., Pacific Tel. & Tel. Co., Seattle, Wash.

Nikiforoff, B., chief elec. engr., Mexican Light & Pr. Co., Mexico, D. F., Mexico.

Ramadanoff, D., research elec. engr., National Carbon Co., Cleveland, Ohio.

Reukema, L. E., prof. of elec. engg., Univ. of California, Berkeley, Calif.

Yarnall, J. H., supt. of pr., Boston Elevated Ry. Co., Boston, Mass.

10 to grade of Fellow

To Grade of Member

Andrews, P. R., elec. engr. II, Tennessee Valley Authority, Knoxville, Tenn.

Badhni, J., engr. & proprietor, Badhni's, Engrs. & Contractors, Tehran, Iran.

Baker, J. R., supt. of pr., Pennsylvania Water & Pr. Co., Baltimore, Md.

Broderson, H. A., elec. engr., L. E. Kurtichanof, Cons. Engr., Portland, Oreg.

Case, N. M., design engr., General Elec. Co., Pittsfield, Mass.

Crosby, D. R., engr., Radio Corp. of America, RCA Victor Div., Camden, N. J.

Dornbush, H. W., head of distribution dept., Pennsylvania Transformer Co., Pittsburgh, Pa.

El Koshairy, M. A., asst. prof., faculty of engg., Fouad I. Univ., Giza, Egypt.

Elliot, W. H., supervising electronics engr., Cutler-Hammer, Inc., Milwaukee, Wis.

Evans, J. N., elec. engr. II, Tennessee Valley Authority, Knoxville, Tenn.

Few, W., mgr., electronics engg., Clark Controller Co., Cleveland, Ohio.

Gardner, M. F., supvr., ind. & cent. sta. engg., Westinghouse Elec. Corp., New York, N. Y.

Gartner, C. E., Jr., junior engr., engg. lab., Philadelphia Elec. Co., Philadelphia, Pa.

Geder, O. S., elec. field & applicat. engg., General Elec. Co., Cleveland, Ohio.

Gibson, F. L., elec. engr., West Virginia Pulp & Paper Co., New York, N. Y.

Gilliam, M. H., vice-pres. & genl. mgr., E. H. Gilliam Co., Charlotte, N. C.

Gogen, S. F., member, bd. of directors, Celik-Boya Co., Kula Textile Mills, Galata, Istanbul, Turkey.

Hurd, O. W., dist. engr., Upper Columbia Dist., Bonneville Pr. Adm., Spokane, Wash.

Johnson, V. O., engr., U. S. Rubber Co., New York, N. Y.

Johnson, W., elec. engr., 523 Heard Bldg., Phoenix, Ariz.

Jones, E. E., research assoc., Iowa State College, Ames, Iowa.

Kandoian, A. G., div. head, Federal Telecommunication Labs., New York, N. Y.

Kang, B. P., research engr., E. I. duPont de Nemours & Co., Arlington, N. J.

Klehanoff, J. H., resident elec. engr., Bureau of Yards & Docks, San Francisco Naval Shipyard, Calif.

Koehler, A. A., design engr., Standard Oil Co., Whiting, Ind.

Lind, W. J., mgr., lamp & lighting div., Canadian General Elec. Co., Vancouver, B. C., Canada.

Manwaring, A. H., exec. vice-pres. & genl. mgr., Philadelphia Elec. & Mfg. Co., Philadelphia, Pa.

Marple, G. N., div. engr., Iowa Public Service Co., Sioux City, Iowa.

McCollum, T. A., engr., Oklahoma Gas & Elec. Co., Ardmore, Okla.

McCormick, H. T., asst. elec. engr., U. S. Bureau of Reclamation, Denver, Colo.

Mikos, J. J., engr., Westinghouse Elec. Corp., East Pittsburgh, Pa.

Milner, G. R., genl. plant mgr., Ohio Bell Tel. Co., Cleveland, Ohio.

Neiman, W. N., dev. engr., General Elec. Co., Pittsfield, Mass.

Nevin, P. P., div. supt. of substations, Southern Calif. Edison Co. Ltd., Alhambra, Calif.

Pappu, V., officer on special duty with gov. of India, c/o Franklin Park Hotel, Washington, D. C.

Peterson, W. L., application engr., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Pettit, J. M., supervising engr., Airborne Instruments Lab., Inc., Mineola, N. Y.

Phillips, C. S., motor engr., Emerson Elec. Mfg. Co., St. Louis, Mo.

Ramaswami, H. K., dy. superintending engr., South Madras Elec. Supply Co., Trichinopoly, S. India.

Ray, W. O., elec. engr. & supt. of maintenance, Todd Houston Shipbuilding Corp., Houston, Tex.

Ringer, F. W., elec. engr., Interstate Oil Pipe Line Co., Shreveport, La.

Rohwer, O. J., elec. engr., Sargent & Lundy, Chicago, Ill.

Rummel, E. T., sales engr., Hertner Elec. Co., Cleveland, Ohio.

Saunders, R. M., instructor, Univ. of Minnesota, Minneapolis, Minn.

Snedeker, M. L., asst. chief engr., The Radiart Corp., Cleveland, Ohio.

Sparling, T. E., elec. engr., asst. to ind. mgr., U. S. Navy, Seattle, Wash.

Stainken, H. A., Sr., design engr., Otis Elevator Co., New York, N. Y.

Storer, S. B., managing engr., Trumbull Elec. Mfg. Co., Norwood, Ohio.

Thomas, J. D., elec. engr., Reynolds, Smith & Hills, Jacksonville, Fla.

Tracy, G. F., prof. of elec. engg., Univ. of Wisconsin, Madison, Wis.

Valle, R. B., Jr., sr. physicist & consultant, Armour Research Foundation, Chicago, Ill.
Weaver, C. E., sr. elec. engr., Eastman Kodak Co., Rochester, N. Y.
White, R. V., field engr., General Elec. Co., Dayton, Ohio.
Wisner, R. R., asst. chief elec. engr., Stone & Webster Engg. Corp., Boston, Mass.
Woodling, G. V., patent attorney, 1340 Union Commerce Bldg., Cleveland, Ohio.
Wright, T. C., pres., Otter Tail Power Co., Fergus Falls, Minn.

56 to grade of Member.

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before September 21, 1946, or November 21, 1946, if the applicant resides outside of the United States or Canada.

To Grade of Fellow

Wade-Cooper, F., General Elec. Co. (India), Ltd., Calcutta, India.

1 to grade of Fellow

To Grade of Member

Allen, D. H., Revere Copper & Brass, Baltimore, Md.
Arthur, F. C., Kansas State Corp. Comm., Topeka, Kans.
Baldwin, L. W., U. S. Navy Electronics Lab., San Diego, Calif.
Barabas, J., Thermoid Co., Trenton, N. J.
Baty, E., The Bell Tel. Co. of Canada, Montreal, Canada.
Bird, D. E., Edmundsons Electricity Corp. Ltd., London, England.
Brown, W. C., SC Engineering Labs., Bradley Beach, N. J.
Browning, L. P., Florida Pr. & Lt. Co., West Palm Beach, Fla.
Davenport, J. F., Southern Calif. Edison Co., Ltd., Los Angeles, Calif.
Eby, J. B. (Re-election), Amer. Tel. & Tel. Co., Philadelphia, Pa.
Feldt, R., Allen B. DuMont Laboratories, Inc., Passaic, N. J.
Fletcher, C. W., Charles T. Main, Inc., Boston, Mass.
Hnilicka, M., Czechoslovak Synthetic Motor Fuel Works, Most, Czechoslovakia.
Koch, J. F., Jr., University of Pennsylvania, Philadelphia, Pa.
Krips, J. A. G., I.T.E. Circuit Breaker Co., Philadelphia, Pa.
Lynskey, J. P., Commonwealth Edison Co., Chicago, Ill.
Maddox, C. H., Radio Station KTBS, Shreveport, La.
Mason, C. J. M., General Motors-Holdens Ltd., Melbourne, Australia.
Minshull, J. A., Boeing Aircraft, Seattle, Wash.
Moorhouse, G. E., University of Melbourne, Melbourne, Australia.
Nadkarni, P. S., University of Washington, Seattle, Wash.
Nordell, R., Sieverts Kabelverk, Sundyberg, Sweden.
Ogle, W. H., Todd Shipyards Corp., Seattle, Wash.
Parsegian, V. L., Portable Products Corp., Brooklyn, N. Y.
Perkinson, T. F., General Elec. Co., Erie, Pa.
Relli, E. D., Chas. T. Main, Boston, Mass.
Rose, M. C., The Chesapeake & Potomac Tel. Co., Baltimore, Md.
Roesel, M. F., Gilbert Associates, Inc., Reading, Pa.
Shahan, J. H., Tampa Shipbuilding Co., Inc., Tampa, Fla.
Sharpe, E. W., Ernest J. Kump, San Francisco, Calif.
Singh, S., Punjab Govt., Lahore, India.
Soulsen, V. C. (Re-election), Penna. Elec. Co., Johnstown, Pa.
Strickenburg, W. F., Meadville Tel. Co., Meadville, Pa.
Sutton, R. C., Pittsburgh Railways Co., Pittsburgh, Pa.
Wamboldt, A. G., N. Y. Telephone Co., Brooklyn, N. Y.
Weise, W. R., Cincinnati Gas & Elec. Co., Cincinnati, Ohio.
West, H. J., Penna. Pr. & Lt. Co., Allentown, Pa.
Williams, B. J., Newton Bros. (Derby) Ltd., Derby, England.

38 to grade of Member

To Grade of Associate

United States

1. North Eastern

Ansevino, L. D., Stone & Webster Engineering Corp. Boston, Mass.
Bowmar, J. A., American Tel. & Tel. Co., Buffalo, N. Y.
Brennan, J. J., Southern New England Tel. Co., Hartford, Conn.
Griffin, D. H., Raytheon Mfg. Co., Waltham, Mass.
Leathers, C. B., General Elec. Co., Providence, R. I.
Martel, C. W., Raytheon Mfg. Co., Newton, Mass.
McIntosh, R. W., 22 W. Wyoming Ave., Melrose, Mass.
O'Connor, R. J., Eastman Kodak Co., Rochester, N. Y.
Pashoorian, S. J., 570 Chestnut St., Lynn, Mass.
Ronan, F. D., Jackson & Moreland, Boston, Mass.
Sanders, J. L., General Elec. Co., Schenectady, N. Y.
Talleur, R. B., Central Hudson Gas & Elec. Corp., Poughkeepsie, N. Y.
True, W. F., Jr., 41 Mechanic St., Foxboro, Mass.
Turitzin, N. M., General Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Althouse, J. W., Jr., Philadelphia Elec. Co., Philadelphia, Pa.
Biscup, J., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Bousky, S., Jack & Heintz Precision Industries, Inc., Maple Heights, Ohio.
Casanova, L. A., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Chiazza, A. C., Westinghouse Elec. Corp., Lima, Ohio.
Emmert, L. R., Westinghouse Elec. Corp., Washington, D. C.
Farmery, B. L., Bra Bon Elec. Co., Philadelphia, Pa.
Gimse, D. R., Navy Dept., Bureau of Ships, Washington, D. C.
Gmeiner, J. R., B. F. Goodrich, Akron, Ohio.
Henderson, J. R., General Elec. Co., Erie, Pa.
Hennessy, J. D., Publicker Industries, Inc., Philadelphia, Pa.
Isbell, J. E., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Kay, A. F., Jack & Heintz Precision Industries, Inc., Cleveland, Ohio.
McElroy, J. H., Gen. Elec. Co., Philadelphia, Pa.
Mitwalli, A. H., Egyptian Education Mission, Washington, D. C.
Merwin, R. E., University of Pennsylvania, Philadelphia, Pa.
O'Neal, M. B., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Rhudy, R. G., General Elec. Co., Philadelphia, Pa.
Rueckert, J. J., Consolidated Gas, Elec. Lt. & Pr. Co., Baltimore, Md.
Samaritino, R. F., 12 Garfield Ave., Collingswood, N. J.
Stehman, J. D., Capital Transit Co., Washington, D. C.
Wasmund, J. A., Westinghouse Elec. Corp., East Pittsburgh, Pa.

3. New York City

Barber, W. H. (Re-election), Standard Oil Development Co., Elizabeth, N. J.
Cammisa, M. A., National Elec. Mfgrs. Assn., New York, N. Y.
Campbell, E. O. (Re-election), Federal Tel. & Radio, Clifton, N. J.
DeAcutis, O., Lt. U.S.M.C.R., 1772 E. 172nd St., Bronx, New York, N. Y.
DeLano, R. W., Jr., Sperry Products, Inc., Hoboken, N. J.
Doehne, R., Public Service Elec. & Gas Co., Newark, N. J.
Glueckler, E. J., Fairchild Camera & Instrument Corp., Jamaica, N. Y.
Levitt, E., Lt. (jg) USNR, 93 Lakeside Drive, Baldwin, N. Y.
Levy, R. J., Arma Corp., Brooklyn, N. Y.
Littlefield, R., Jr., E. I. duPont, Grasselli, N. J.
Murphy, E. J., Lieut., USNR, 36 Kings Rd., Chatham, N. J.
Rolnik, S., 20 E. 18th St., Brooklyn, N. Y.
Shepherd, R. L., Public Service Elec. & Gas Co., Newark, N. J.

4. Southern

Barnes, I. M., Jr., Tennessee Valley Authority, Chattanooga, Tenn.
Barney, J. M. (Re-election), N.A.C.A., Langley Field, Va.
Bevis, J. M., Tennessee Eastman Corp., Oak Ridge, Tenn.
Bishop, J. R., Mutual Boiler Insurance Co., Spartanburg, S. C.
Burnett, W. C., Southern Bell Tel & Tel. Co., Charlotte, N. C.
Cline, J. T., Carbide & Carbon Chemicals Co., Oak Ridge, Tenn.
Gregg, J. L., Jr., Alabama Pr. Co., Birmingham, Ala.
Noble, H. F., Jr., Virginia Elec. & Pr. Co., Norfolk, Va.
Patton, H. S., Carbide & Carbon Chemical Corp., Oak Ridge, Tenn.
Prescott, B. W., Alabama Pr. Co., Birmingham, Ala.
Rader, J. F., Jr., Columbia Elec. Repair Co., Columbia, S. C.
Randolph, C. R., Florida Pr. & Lt. Co., West Palm Beach, Fla.
Rutherford, J. B., Howard M. Patterson, Decatur, Ga.
Warren, A. L., Southwestern Gas & Elec. Co., Shreveport, La.
Whitmore, C. W., Jr., 1726 S. W. 19th Ave., Miami, Fla.

5. Great Lakes

Bartha, S. J., Automatic Elec. Co., Chicago, Ill.
Bonney, R. H., Caterpillar Tractor Co., Peoria, Ill.
Brown, C. W., Gen. Elec. Co., Fort Wayne, Ind.
Clapp, L. R., AC Spark Plug Div. of G.M.C., Flint, Mich.
Cummings, W. J. (Re-election), Public Service Co. of Indiana, Inc., Indianapolis, Ind.
Dietz, G. E., 2468 West Auer Ave., Milwaukee, Wis.
Gaston, E. E., Sun-Kraft, Inc., Chicago, Ill.
Holmes, T. W., Minn. Pr. & Lt. Co., Duluth, Minn.
Jeffries, A. W., Wisconsin Pr. & Lt. Co., Baraboo, Wis.
Kolon, E. C., Colonial Elec. Co., Detroit, Mich.
Laskin, S., Minn. Pr. & Lt. Co., Duluth, Minn.
Lochard, G. M., Illinois Pr. Co., Decatur, Ill.
Mierendorf, R. C., Square D Co., Milwaukee, Wis.
McElroy, J. O., Minn. Pr. & Lt. Co., Duluth, Minn.
Oberlander, E. B., Oberlander Elec. Co., Peoria, Ill.
Pettit, G. A., Sargent & Lundy, Chicago, Ill.
Rose, D. A., Electronic Service Co., Flint, Mich.
Spurbeck, G. B., Minn. Pr. & Lt. Co., Duluth, Minn.
Taylor, J. E., Allis-Chalmers Mfg. Co., West Allis, Wis.
Thatcher, J. D., Electronic Service Co., Flint, Mich.
Tibbetts, C. H., Minn. Pr. & Lt. Co., Duluth, Minn.
Turnquist, A. A., Minn. Pr. & Lt. Co., Duluth, Minn.
Votaw, E., Oliver Corp., South Bend, Ind.

6. North Central

Ballard, R. R., Public Service Co. of Colo., Denver, Colo.
Carpenter, E. K., Public Service Co. of Colo., Denver, Colo.
Lappi, T., U. S. Bureau of Reclamation, Denver, Colo.

7. South West

Chandlee, J. M. (Re-election), Century Elec. Co., St. Louis, Mo.
Davis, L. K., Fisk Elec. Co., Houston, Tex.
Houston, C. E. (Re-election), Texas Tech. College, Lubbock, Tex.
Huckins, G. J., Western Elec. Co., Dallas, Tex.
Roberts, B. W., 500 North 10th, Frederick, Okla.
Welborn, R., Jr., J. & J. Armature Works, Beaumont, Tex.

8. Pacific

Andrews, M. J., Dept. of Water & Pr., Los Angeles, Calif.
El-Sum, H., Calif. Institute of Tech., Pasadena, Calif.
Feldman, S., Douglas Aircraft, Santa Monica, Calif.
Ferguson, A. E., Headman, Ferguson & Carollo, Phoenix, Ariz.
Goggin, T. M., Placer Management, Ltd., San Francisco, Calif.
Haruff, G. E., Pacific Gas & Elec. Co., Emeryville, Calif.
Olson, O. E., Ensign, U.S.N., USS *Duluth*, c/o F.P.O., San Francisco, Calif.
Paine, O. S., Modesto Irrigation District, Modesto, Calif.
Rowland, W. H., Western Pipe and Steel, South San Francisco, Calif.
Sattro, R. L., Sr., Consolidated-Vultee Aircraft Corp., San Diego, Calif.
Wartena, R. S., Oakland Army Base, Oakland, Calif.

9. North West

Edwards, D. E., Seattle Light Dept., Seattle, Wash.
Fletcher, J., General Cable Corp., Seattle, Wash.
Hughes, R. C., Hughes Elec. Co., Spokane, Wash.

Elsewhere

Bhowmic, M. C., Cooch Behar State, Bengal, India.
Dalen, G., Aga-Baltic AB, Lidingo, Sweden.
Dalmau M., L., The Mexican Lt. & Pr. Co., Ltd., Mexico D. F., Mexico.
Dehnugara, P. P., The English Elec. Co., Ltd., Fort, Bombay, India.
Dmitrieff, N. I., Shanghai Pr. Co., Shanghai, China.
Flindt, C. B., RAF Station, Melksham, Wiltshire, England.
Kuyt, A., Modder East Gold Mine Ltd., Transvaal, South Africa.
Lundbaeck, N. T., Svdsvenka Kraftaktiebolaget, Malmo, Sweden.
Mackey, P. J., 40 Lesson Park, Ballsbridge, Dublin, Ireland.
Marshall, R. V., Messrs. Newton Bros. (Derby) Ltd., Derby, England.
Mehta, B. D., The Darbhanga Laberia Seral Elec. Supply Corp., Ltd., Darbhanga, Bihar, India.
Padmanabhan, R., Vincent Radio Engineering College, Trichinopoly, So. India.
Pereira, T. B., Fertilizers and Chemicals, Ltd., Alwaye, Travancore, S. India.
Rodriguez, R., P. O. Box 67, San Juan, Puerto Rico.
Vinogradov, N. A., Shanghai Pr. Co., Shanghai, China.
Williams, D., South Porto Rico Sugar Co., Ensenada, Puerto Rico.

Total to grade of Associate
United States, 110
Elsewhere, 16

OF CURRENT INTEREST

Engineering Societies Library Describes Services Offered

As part of his efforts to give needed publicity to the unique research facilities latent in the Engineering Societies Library in New York, N. Y., Ralph H. Phelps, acting director of the library, addressed the meeting of officers, delegates, and members at the AIEE summer convention in Detroit. He stressed the fact that, as the foremost engineering library in the United States, its services are available to engineers throughout the United States, whether or not they are members of a Founder Society, and whether or not they can visit the library.

In this same connection the library has issued a pamphlet describing and explaining in detail the services it provides for those desiring technical information.

READING ROOM

Anyone may visit the free reading room and use all the resources of the library. A trained staff is ready to help the reader and to direct him to the best sources, so that he will not waste time in aimless searching. The reading room opens at 10 a.m. weekdays. Mondays to Fridays it closes at 10 p.m. and Saturdays at 6 p.m., except during the summer, when it closes at 5 p.m. every day. It is closed on Sundays and most legal holidays.

SERVICE BUREAU

Distance and lack of time prevent many from coming to the library. To serve these persons, a specially trained staff is available to make literature searches, translations, and copies of library material. All services are rendered at cost.

Searches. The service bureau handles questions on any engineering subject that can be answered by consulting the existing technical literature. This service ranges from recommending books on a specific subject to the preparation of comprehensive annotated bibliographies. The original publication, if available in the library, is examined and is listed only if it is pertinent to the search. Literature searches are made for all purposes including that of disclosures related to patents.

Searches are undertaken to suit the exact specification of the inquirer. To do this the searchers must know:

1. The subject, stated as exactly as possible with indication of those phases to be included and those, if any, to be excluded. Should the subject be covered very thoroughly, or will a less complete search suffice?
2. Period of time to be covered.
3. Is the search to cover materials in all languages or only in English? Is it to be restricted to material from any country or countries?

The charge for searching is $2.50 per hour, except to members of a Founder Society. On request, the cost of covering a given field for a given period will be estimated, if the nature of the search makes this possible. A charge is made only for the time used.

Translations. The rates charged per hundred words for English translations of technical articles of ordinary difficulty are:

German, French, Dutch, Italian, Spanish	$1.00
Russian, Polish, Portuguese, Danish, Swedish, etc.	1.20
Japanese	3.00

A small additional charge will be made for the extra time required for articles that contain a high proportion of formulas or other difficult material. The cost of any translation will be estimated if requested, but time can be saved by indicating in letters of inquiry the amount you are willing to pay. If this is sufficient to cover the cost, the work of translating can begin at once. The cost will be the same whether or not an estimate is supplied, as the work is done at cost.

Photostats and Microfilm. Photostatic copies of material in the library can be supplied for 30 cents a print. This price is for 11 by 14 inch, white on black (negative) prints. Any two facing pages which together measure not over 11 by 14 inches can be taken on one print. Larger material will require one print per page. Black on white (positive) prints cost an additional 30 cents each. Reductions or enlargements can be supplied.

Microfilm is economical for copying long articles; photostating is generally preferable for short ones. As most technical articles are short, the library does not have equipment for microfilm copying, but by arrangement with another organization, the library can supply microfilm copies of its material. Any one article from a magazine can be supplied for $1.50, regardless of the length of the article.

Payment for Services. As all services are rendered at cost, payment in advance is requested when the exact cost of the work is known. Invoices will be sent when payment in advance is impracticable.

SPECIAL RATES AND SERVICES FOR MEMBERS OF THE FOUNDER SOCIETIES

The Engineering Societies Library is supported largely through the allotment of a portion of the dues of the members of the Founder Societies (American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, and the AIEE). For this reason individual members of these societies receive special rates on services, and they may borrow library books. Minor requests from members are handled without charge. All other services of the library are also available to members.

Rates. Members of the Founder Societies who order work for their personal use and pay by personal check will receive:

1. A discount of 20 per cent on searches.
2. A discount of 20 per cent on translations.
3. A reduction of 5 cents on each photostat print.

Loans of Books. Because the library's material is valuable and much of it in frequent demand, the library board has established the following rules governing the loan of books:

1. Books, including bound serial publications, may be borrowed by any member of a Founder Society, if he is in good standing and residing in the continental United States or Canada. (Applicants are asked to name their society affiliation.)
2. A charge of 25 cents a week, or fraction of a week, will be made for each volume borrowed.
3. The maximum length of time for any loan is two weeks, not counting time in transit.
4. Members may have as many as three volumes on loan at one time.
5. Return postage and insurance must be paid by the borrower.
6. Rare books and reference books are lent only after approval by the library board.

Requests should be addressed to the Engineering Societies Library, 29 West 39th Street, New York 18, N. Y.

60-Cycle Power Reaches Rumford, Me.

A historic "last" is claimed by the Rumford Falls Light and Water Company, Rumford, Me., in announcing the impending conversion of its domestic electricity supply from 40-cycle to 60-cycle power. It claims to be the last company in the United States to make the change, which will affect 5,000 customers.

The 60-cycle conversion was not made previously, because the Rumford Falls Light and Water Company takes only four per cent of the output of the Rumford Falls Power Company, while the remaining 96 per cent goes to the Oxford Paper Company which will continue to use 40-cycle power.

Complete conversion will require an estimated 36 months at a cost of approximately $500,000. A consumer survey is being conducted by mail in order to determine what electric appliances in homes will need to be converted to use the new current. The company plans to convert such appliances at no charge to its customers or to make allowances for 40-cycle appliances on the purchase of new appliances.

Engineers' Co-operation Sought in Economics Status Survey

In a self-analysis of unprecedented magnitude, America's engineering profession in co-operation with the United States Department of Labor's Bureau of Labor Statistics, is conducting a survey on the economic status of the nearly 100,000 members of the societies comprising Engineers Joint Council—the American Institute of Chemical Engineers, the AIEE, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, and the American Society of Mechanical Engineers. The National Society of Professional Engineers also is participating in the survey.

Calling for information which can be supplied readily and simply, the questionnaire is being mailed to each member of the participating engineering bodies, together with an explanatory letter signed by Ewan Clague, Commissioner of Labor Statistics. Replies will be tabulated by code on machines in the Bureau which are designed especially for such work.

The questionnaire is accompanied by an addressed envelope for the convenience of recipients.

The physical conduct of the survey is in the hands of the Bureau of Labor Statistics, which is equipped to handle this type of precoded questionnaire, in which participants remain anonymous. The committee has engaged as consultant and liaison with the Bureau, Andrew Fraser, Washington, D. C., who prepared a comprehensive report on a similar survey conducted by the Bureau in 1935.

An up-to-date foundation for evaluating the educational needs and professional opportunities of the engineering profession is the objective of the survey, which is under way after more than a year of preparation and study. The undertaking is sponsored by Engineers Joint Council's Engineer Survey Committee, a subcommittee of the EJC Committee on the Economic Status of the Engineer. Colonel William N. Carey, executive secretary of ASCE, is chairman.

The committee urges each engineer to answer the questions completely; and to do it as soon as the questionnaires are received.

Emphasis is placed on the need for complete and correct responses to the questionnaire, since anonymity makes checking impossible, and incompleteness, even of one question, automatically excludes all other data in the question from tabulation.

A deadline for receipt of completed questionnaires has been set for November 15, after which Mr. Fraser will proceed with preparation of a report based on the replies. Each member is requested to give the matter immediate attention.

THE 1946 SURVEY OF THE ENGINEERING PROFESSION

Committee On The Economic Status Of The Engineer
ENGINEERS JOINT COUNCIL

Cooperative Project In Cooperation With The

Bureau Of Labor Statistics
U.S. DEPARTMENT OF LABOR
Washington 25, D. C.

NOTE 1: Questions 2 to 9 inclusive require merely that you circle one and only one of the code numbers.

1. AGE LAST BIRTHDAY (in years) _____

2. SEX: Male . . . . . 1 Female 2
(Circle one and only one of these two code numbers)

3. YEAR OF ENTERING PROFESSION: Indicate below the year in which you drew your first salary in your professional field.
1900 (or before) = 00
19 - 00 01 02 03 04 05 06 07 08 09
10 11 12 13 14 15 16 17 18 19
20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35 36 37 38 39
40 41 42 43 44 45 46
(Circle one and only one of these forty-eight code numbers)

4. FORMAL EDUCATION IN A NON-ENGINEERING FIELD: If you received education in a non-engineering field indicate below the highest educational level reached by you (excluding honorary degrees).
Doctor . . . . . 1 Master 2
Bachelor . . . . 3 Incomplete College . . . 4
(Circle one and only one of these four code numbers)

5. FORMAL EDUCATION IN A BASIC ENGINEERING FIELD: Indicate below the highest educational level reached by you in a basic engineering field (excluding honorary degrees).

Basic engineering field	Educational Level: Doctor	Master	Bachelor	Incomplete college training	No college training	
Chemical engineering	11	12	13	14	15	
Civil engineering	21	22	23	24	25	(Circle one and only one of these thirty code numbers)
Electrical engineering	31	32	33	34	35	
Mechanical engineering	41	42	43	44	45	
Mining and metallurgical engineering	51	52	53	54	55	
Any other engineering field	61	62	63	64	65	

6. VETERAN STATUS:
Are you a Veteran of World War II? Yes . . . . . 1 No 2
(Circle one and only one of these two code numbers)

NOTE 2: In answering questions 7 to 12 inclusive, do not insert any code numbers for years prior to the one when you drew your first salary in your professional field which you circled in Question 3.

7. EMPLOYMENT LOCATION: Insert in box for the appropriate year or years one and only one code number corresponding to the location in which you were employed for the major part of that year.

MR. ENGINEER—Do not fail to answer this questionnaire, which should be reaching you in the mail any day now, if you have not received it already. It is not "just another government questionnaire." It is a study being made by YOUR society and paid for in part by YOUR dues. The questionnaire comes to you from the United States Department of Labor's Bureau of Statistics because that bureau, which is equipped to conduct and tabulate the findings of such coded surveys, is co-operating with the AIEE and other engineering societies in this task of evaluating the economic status of the engineer in 1946

Enemy Air Equipment Exhibited at Wright Field

To facilitate the exploitation of captured enemy aeronautical equipment and data, the United States Air Technical Intelligence has arranged a symposium for September 9 to 13 at Air Matériel Command headquarters, Wright Field, Dayton, Ohio.

The meeting is one of a series intended to give representatives of American industry, agencies, and institutions opportunity to participate in technical studies, discussions, and close-up inspections of equipment in which they are particularly interested.

Most of the equipment exhibited at the meetings is available for loan in exchange for technical reports on studies and tests made by the beneficiaries. Air Technical Intelligence disseminates all available pertinent information, in accordance with the Government's co-ordinated program covering all types of captured information and equipment.

The Equipment Symposium, as the September meetings are termed officially, has been organized and will be conducted by the equipment section, analysis division. In order that visitors may budget their time, sessions have been scheduled under the following dates and general headings:

September 9—Instrument and navigation and electric (not electronic) equipment.

September 10—Mechanical and ground (handling) equipment, aeronautical materials.

September 11—Personal equipment.

September 12—Aeromedical equipment.

September 13—Photographic equipment.

Inspections will precede and follow lecture-discussion periods, and procurement procedures will be explained. Tours of the flight line also will be arranged. Displays are in charge of the receiving and storage section, collection division.

Equipment in the following categories will be discussed and examined under guidance of intelligence personnel and visiting experts:

Instrument and Navigation Equipment

Autopilots.
Compasses (magnetic and remote indicating).
Chronometers.
Indicators (air speed, rate of climb, bank and turn).
Gauges (pressure, vacuum, hydraulic) and signal assemblies.
Gauges (for fuel level, water, and oil).
Thermometers.
Watches.
Tachometers, tachometer generators.
Thermocouples.
Voltmeters.
Sextants.
Astro and pocket compasses.
Fuel mixture indicators and analysis cells.
Indicators, position (landing gear and flap).
Computers (except armament).
Navigation kits.

Electric Equipment

Generators, starters, inverters, converters.
Motors and alternators.
Test and maintenance equipment.
Batteries, power cable, connectors.
Lightning equipment, aircraft and airdrome.

Powerful Traveling Wave Tube Developed

Developed by Bell Telephone Laboratories, Inc., this new vacuum tube amplifier is expected to have widespread applications in long-distance telephony, especially in microwave radio-relay systems, and in television transmission. The tube promises to amplify voice or television signals over a frequency band 40 times as wide as that of the best tube now in use and to give many times the amplification. A little more than a foot long and a few inches wide, the tube contains a coil of thin wire running the length of the stem. The wave to be amplified is fed onto this coil at the bulb end and drawn off at the other end. The idea underlying the traveling wave tube was conceived by R. Kompfner of the Clarendon Laboratories at Oxford University and the electronic problems were solved by J. R. Pierce and L. M. Field of Bell Laboratories

Protective devices for electric equipment.
Electric system control devices.

Mechanical and Ground Handling Equipment
Aircraft heating and ventilating equipment.
Anti-icing and deicing equipment.
Maintenance stands and allied equipment.
Pressurized cabin equipment, including regulators, cabin superchargers.
Power and hand tools.
Auxiliary power plants, generators, battery carts.
Portable and fixed aircraft fire extinguisher equipment.
Compressed air and internal combustion starters.
Precision measuring equipment (except optical).

Materials
Metals and metal working.
Radiographic and magnetic inspection.
Rubber (natural and synthetic).
Vibration absorbers.
Leather.
Forgings, castings.
Corrosion control.
Bearings (ball and sleeve).
Plastics and resins.
Chemicals.
Wood.
Metallurgy and plating.
Welding and welding materials.
Adhesives.
Paints and dyes.
Textiles.
Ceramics.

Personal Equipment
Parachutes.
Flying clothing (including electrically heated suits).
Arctic, jungle, sea, and land rescue equipment, life rafts, vests, accessories.
Aerial delivery containers and equipment.

Bell System Expands Mobile Service Plans

Applications have been filed with the Federal Communications Commission by the American Telephone and Telegraph Company for authority to construct transmitter–receivers for mobile radiotelephone service along the highways between Washington and New York; Buffalo and New York, via Albany; and Los Angeles and San Diego. Construction on similar installations already has been started between New York and Boston and between Chicago and St. Louis. When completed and licensed, the systems will provide radiotelephone service to properly equipped cars, trucks, busses, boats, and trains operating anywhere along or near the entire route.

On the New York–Washington highway, it is planned to build stations near New Brunswick, Philadelphia, Wilmington, Baltimore, and Washington, as an extension of the Boston to New York system. On the New York–Albany–Buffalo route, stations are to be located near White Plains, Poughkeepsie, Albany, Fonda, Utica, Syracuse, Rochester, and Buffalo. Between Los Angeles and San Diego, transmitter–receivers will be erected on Mount Wilson and Mount Woodson.

Applications for Bell System highway mobile radiotelephone installations in a number of other cities are pending or in preparation. Those communities include Cleveland, Columbus, Lansing, Saginaw, Grand Rapids, Rockford, Knoxville, Chattanooga, Charleston, Savannah, Jacksonville, Montgomery, Mobile, Baton Rouge, Shreveport, Little Rock, Tulsa, and Austin. Although these stations will operate initially as separate installations serving only vehicles in and around each community, they are expected eventually to become links in mobile radiotelephone systems on important through highways.

Telephone calls to and from vehicles will travel part way by radio and part way by wire, each transmitter–receiver being linked by wire with a telephone central office. A man in New York, for example, who wants to call a mobile unit en route between New York and Washington will dial "long distance" and ask for the mobile service operator, to whom he will give the telephone number of the vehicle and its estimated location. The call will be routed over telephone wires to the operator at the transmitting station nearest the car or truck. In a similar manner, a call may be placed from a vehicle to any telephone, or between two vehicles.

Navy Reveals War Use of Infrared Telescopes

Telescopes constructed around the same infrared image tube as the sniperscope and the snooperscope (*EE, June '46, p 295*) were employed by the United States Navy during the war to make night landings on beaches bathed with infrared floodlights and for signaling after dark. The telescopes, upon which development was started in the early 1930's, were manufactured by the Radio Corporation of America.

On August 25, 1942, the various applications of infrared equipment were tested in a complete amphibious landing operation staged off Solomon's Island, Md. Signaling by use of marker lights and identification lights, and reconnaissance by means of large infrared searchlights, were demonstrated. In later demonstrations it was shown that it is possible to see a shore line and buildings along a coast and to detect trucks, tanks, and other large vehicles. This and other Navy tests established the infrared electron telescope as a practical weapon of war.

As the sensitivity of the tubes and telescopes was improved, the RCA company perfected complete portable units consisting of a small spotlight and a hand-borne infrared telescope, which were used by the Navy in many applications.

In addition to the uses found for infrared by the Navy, other wartime applications of the electron telescope include the marking of landing places for paratroopers by members of the advance party, and the spotting of camouflage nets and other devices deceptive to the unaided human eye.

Infrared peacetime applications include burglar alarms, microscopy, spectroscopy, examination of undeveloped film in total darkness, and special undercover work in connection with police investigation and apprehension of criminals.

Static Electricity From Snow Is Air Communication Hazard

The breaking up of snowflakes into minute particles as they strike an airplane in flight creates sufficient static electricity to account for the interruption of radio voice communication between an airplane and the ground, one of the greatest hazards of flying in a snow storm, according to the results of a study made by Vincent J. Schaefer of the General Electric Company, Schenectady, N. Y.

Experiments have shown that snowflakes do not follow the air-flow pattern of an airplane in flight, but instead hit the airplane and break into from 30 to 500 fragments. On breaking up they produce the static electricity which drowns out all other radio signals.

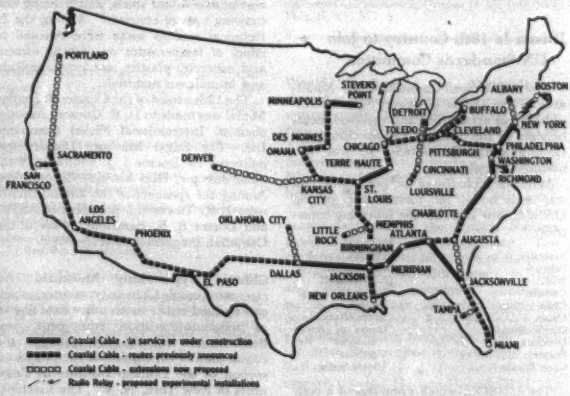
Snowflakes generally are classified into two types based on the atmospheric electric effects which occur during snow storms. A positive electric charge is associated with crystal forms of dry snow which make up cirrus clouds. Both positive and negative electricity are associated with a snow storm characterized by wet stellar crystals often coated heavily with rime, ice needles, graupel, sleet, and powder snow.

A comparison was made of the amount of electricity carried by the snow from the sky and the amount created by friction when the snow particles are broken up, showing that on an average a snow crystal carries a charge equivalent to 17,500 electrons. The fracture of the crystal raises this average charge by more than a hundred times in some instances.

FPC Compiles Electric Rates for 1945. The Federal Power Commission has issued its 12th annual publication showing, in the form of typical net monthly bills, electric rates as of January 1, 1946, for residential, commercial light, commercial power, and industrial service in 204 United States cities having populations of 50,000 and more. If the population of these cities plus the population of communities served under identical rates is taken into account, the data presented are applicable to about 75 per cent of the electric customers living in communities of 250 population and more. The report, R-31, is priced at 25 cents a copy and may be obtained from the Federal Power Commission, Washington 25, D. C.

16 Millimeter Films Shown in Hollywood. Regular showings of feature length motion pictures in 16 millimeter size recently were inaugurated at the Marcal Theater in Hollywood, Calif. Projection room installations, manufactured by the Bell and Howell Company, Chicago, Ill., were dual 16 millimeter Filmoarc machines. The pictures were reproduced on a standard 16 by 22 foot theater screen with a projection throw of 123 feet.

Bell System Network for Television Grows



Recent extensions of the Bell System coaxial network include cables between New York and Washington and between Atlanta and Jacksonville. Cables are under construction between Washington and Charlotte and between Atlanta and Fort Worth, and by the end of this year construction will be well along on the link from Fort Worth to Los Angeles. Experience in the operation of a coaxial television network has been gained through experimental use of these facilities. On December 1, 1945, the Army and Navy football game at Philadelphia was picked up and transmitted over coaxial cable to New York for broadcast. On February 12, the Lincoln Day ceremonies at Washington were picked up at several spots alternately, broadcast through a Washington station, and transmitted over coaxial cable to New York and there broadcast from two television stations. On April 15, television for the first time was transmitted in both directions between New York and Washington, programs being originated alternately at studios in the two cities and broadcast simultaneously at both points. On April 19, another milestone was passed when color television was sent over the coaxial cable from New York to Washington and back, and broadcast from the transmitter in New York.

JOINT ACTIVITIES

Second Electronics Conference in Chicago, Ill., October 3–5

Approximately 60 technical papers will be presented at the second annual National Electronics Conference at the Edgewater Beach Hotel, Chicago, Ill., October 3–5, 1946. Sponsors of the conference define its purpose as that of "a national forum on electronic research, development, and application."

The conference is planned to provide technical meetings for the presentation of original papers covering latest developments in electronics and applications of electronic apparatus; forums for the review and correlation of recent progress in the many branches of the field; and symposia for the interchange of ideas, methods of approach, and technique among scientists, electronic engineers, and others working in different fields of application.

Subjects for the scheduled sessions included television, antennas and wave propagation, microwave generators, mobile radio communication, infrared communication systems, high-frequency heating, recording and facsimile, nuclear physics, and medical and industrial applications. Though several sessions will run concurrently, the program has been arranged to minimize the overlapping of papers on related topics.

Among the prominent speakers at the conference will be: Doctor E. U. Condon (M '44) director of the National Bureau of Standards; Doctor Frederick L. Hovde, president of Purdue University; Doctor C. G. Suits (M '41) vice-president of the General Electric Company; and Doctor J. O. Perrine, vice-president of Bell Telephone Laboratories, Inc.

Adding interest to this year's conference will be a display of manufacturers' exhibits. The exhibits will consist of educational ap-

proaches to various electronic subjects and demonstrate recently developed electronic equipment. The exhibitors are manufacturer of electronic equipment in communications, power, television, instrumentation, industrial processes and controls, and transportation. Other displays will present recent applications of electronics in medicine and related fields.

Those planning to attend the conference are asked to make advance registration by mail prior to September 19. No registration can be accepted after that date. Advance remittance of $14 will cover all conference activities, including a copy of the "Proceedings," and should be sent to E. H. Schulz, secretary, Technology Center, Chicago 16, Ill. No advance registration will be considered without remittance.

The National Electronics Conference is sponsored by the Illinois Institute of Technology, Northwestern University, and the University of Illinois together with the Chicago Sections of the Institute of Radio Engineers and the AIEE. Doctor J. E. Hobson (M '41) Armour Research Foundation, is chairman of the board of directors of the conference, and W. O. Swinyard, Hazeltine Electronics Corporation, is the president. W. M. Ballenger (M '38) of the General Electric Company; R. J. Donaldson (M '44) of Northwestern University; and E. O. Neubauer (M '44) of the Illinois Bell Telephone Company are representing the AIEE Chicago Section on the executive committee. Other officers and directors are:

Doctor R. E. Beam (A '42) Northwestern University; Doctor A. B. Bronwell (M '44) Northwestern University; A. Crowley, consulting engineer; Doctor C. A. Crowley, Graham, Crowley and Associates; C. A. Emery, Westinghouse Electric Corporation; Professor G. H. Fett, University of Illinois; R. H. Herrick, Lorain Telephone Company and Lorain Radio Company; Cullen Moore, Galvin Manufacturing Corporation; Doctor L. T. Rader (M '43) Illinois Institute of Technology; Doctor C. S. Roys (M '45) Illinois Institute of Technology; Professor E. H. Schulz (M '43) Illinois Institute of Technology; O. Werterberg, Commonwealth Edison Company.

Engineering Council for New York. Organization of the Engineering Societies Council of New York, comprising delegates from the local chapters of engineering, scientific, and technical societies, recently was completed. The council is intended to enable the engineering profession to produce a better co-ordinated program in Greater New York in the public interest as well as that of the members of the participating organizations. It is the direct outgrowth of the Engineering Societies Committee on War Production, through whose efforts a number of successful clinics on technical problems were held during the war. Names of the officers chosen and the societies they represent follow:

Chairman—H. G. R. Carlson, American Society of Mechanical Engineers.

Vice-Chairman—H. P. Wall, American Society of Safety Engineers.

Secretary—M. P. Davis, American Society for Testing Materials

Treasurer—H. F. Dart (M '26) Institute of Radio Engineers.

Directors—O. B. J. Fraser, American Institute of Mining and Metallurgical Engineers; E. J. Lyons, American Institute of Chemical Engineers; W. F. O'Connor, American Chemical Society; C. S. Purnell (M '35) American Institute of Electrical Engineers; H. J. Ryan, American Society of Heating and Ventilating Engineers; and E. M. Sherwood, American Society for Metals.

AIEE delegates to the council are W. J. Barrett (M '36) and C. S. Purnell. M. D. Hooven (F '44) and J. L. Callahan (M '35) are alternates.

ASA Revises Standards List. A revised list of Standards approved to date has been published by the American Standards Association. The 845 Standards listed in the booklet include definitions of technical terms, specifications for metals and other materials, dimensions, safety provisions for the use of machinery, methods of work, and methods of test for the finished product. The list will be sent free of charge to anyone interested. Requests should be addressed to the American Standards Association, 70 East 45th Street, New York 17, N. Y.

OTHER SOCIETIES •

Russia Is 18th Country to Join UN Standards Committee

The All-Union Committee on Standards of the Union of Soviet Socialist Republics has applied for and received membership in the United Nations Standards Co-ordinating Committee, it was announced recently.

With the inclusion of the Soviet national standards body, the membership of the UNSCC now includes the following countries:

Australia	Mexico
Belgium	Netherlands
Brazil	New Zealand
Canada	Norway
Chile	Poland
China	South Africa
Czechoslovakia	Union of Soviet Socialist Republics
Denmark	United States
France	
Great Britain	

The UNSCC, which grew out of a conference of the national standards bodies of the United States, Canada, and Great Britain toward the end of the war, has expanded to include the national standards bodies of the other United Nations as they applied for membership. A draft constitution for a permanent international standards organization drawn up by UNSCC is being examined by the member bodies.

Pending the adoption of the constitution, standardization projects are being studied by the committee. A proposal for an international standardization program for textiles recently was submitted to the committee by the American Standards Association, American representative on the UNSCC. Other projects in process of study are: metal food containers; moisture regain of wool; definition o the term rayon; terms and definitions relating to the heat treatment of steel; plastics terminology; radio interference suppression; airfield lighting, identification, colors, and marks; filling ratios and valve outlets for gas cylinders; standards simplification of shellac grades and methods of testing the properties of shellac; standards for sheet and wire gauges; standard voltages above 220 kv; machine tools; unification of boiler construction codes; automobile standards; building standards; and documentation.

Successful Meeting Held in Buffalo by ASTM

An attendance of 1,825, second only to 1944 as an annual meeting record, was reported from the meeting of the American Society for Testing Materials held in Buffalo, N. Y., in June.

Eight symposiums, with from 4 to 15 technical papers presented at each, were held. Topics discussed included: bearings, gas turbine materials, fatigue, spectroscopic light sources, oil procurement practices, testing parts and assemblies, pH measurements, atmospheric weathering of corrosion-resistant steels, and freezing and thawing tests of concrete. Among the 25 technical sessions some were devoted to effect of temperature on metals, cement and concrete, plastics, nonferrous metals, and bituminous materials.

The 19th award of the Charles B. Dudley Medal was made to H. R. Copson, research chemist, International Nickel Company, Inc. The Edgar Marburg Lecture was delivered by Doctor J. J. Mattiello, technical director, Hilo Varnish Corporation. Among the speakers at the annual dinner were J. R. Townsend, president of ASTM and Doctor B. K. Sandwell, editor of the Canadian magazine, *Saturday Night*.

Chinese Typewriting Machine. An electroautomatic Chinese typewriter, which can be used either as an office machine or as telecommunication equipment, was demonstrated for the first time at the recent annual convention of the American section of the Chinese Institute of Engineers in New York, N. Y. The machine, designed by International Business Machines Corporation, Poughkeepsie, N. Y., makes it possible for an experienced operator to type at the rate of 40 to 45 Chinese words a minute. Some 5,400 ideographic type faces are engraved upon a cylinder in the typewriter in vertical and horizontal rows. The machine is operated with a keyboard of 43 keys. The 36 numerical keys are divided into four groups and any character can be placed in the printing position by striking one key in each group, the first determining the thousands digit, the second the hundreds digit, the third the tens digit, and the fourth determining the unit digit and operating the typing mechanism. The characters are arranged on the drum in three groups, according to the frequency with which they are used.

The first group, comprising 1,000 characters, represents 90 per cent of the ideographs used in ordinary Chinese correspondence.

Edison Foundation Organized. Announcement has been made of the incorporation of the Thomas Alva Edison Foundation "for the advancement of education and scientific research." Officers of the foundation are:

President—C. F. Kettering (F '14) vice-president in charge of engineering, General Motors Corporation.

Vice-Presidents—T. J. Watson, president, International Business Machines Corporation; K. T. Compton (F '31) president, Massachusetts Institute of Technology; R. C. Clothier, president, Rutgers University; Gano Dunn (HM '45) president, J. G. White Engineering Corporation; F. F. Tait (F '12) chairman, Dayton Power and Light Company.

Treasurer—W. W. Freeman, president, Edison Pioneers.

Secretary—John Edison Sloane, grandson of the inventor.

Mrs. Thomas Alva Edison, widow of the inventor, was elected honorary chairman; his daughter, Mrs. John Eyre Sloane, was elected honorary vice-chairman, and his son, former Governor Charles Edison, honorary president.

Chemists Elect Officers. The American Institute of Chemists recently elected the following officers to serve for the coming year:

President—Doctor Foster D. Snell, president of Foster D. Snell, Inc., Brooklyn, N. Y.

Vice-President—Doctor Joseph Mattiello, technical director, Hilo Varnish Company.

Secretary—Doctor Lloyd Van Doren, patent attorney, New York, N. Y.

Treasurer—Frederick A. Hessel, president, Montclair (N. J.) Research Corporation.

New councilors elected for three years were:

Doctor Donald B. Keyes, vice-president, Heyden Chemical Corporation; Doctor Raymond E. Kirk, dean of the graduate school and head of the department of chemistry, Polytechnic Institute of Brooklyn (N. Y.); and Doctor Donald Price.

ASTM Elects Officers for 1946–47. Announcement of the election of officers for 1946–47 was made at the 49th annual meeting of the American Society for Testing Materials in Buffalo, N. Y., in June. The officers for the coming year will be:

President—Arthur W. Carpenter, manager of testing laboratories, B. F. Goodrich Company, Akron, Ohio.

Vice-President—Richard L. Templin, assistant director of research and chief engineer of tests, Aluminum Company of America, New Kensington, Pa.

Directors—A. G. Ashcroft, director of research, Alexander Smith and Sons Carpet Company, Yonkers, N. Y.; A. T. Chamerovy, manager of laboratory, Sears, Roebuck and Company, Chicago, Ill.; J. H. Foote (F '32) supervising engineer, Commonwealth and Southern Corporation, Jackson, Mich.; F. E. Richart, research professor of engineering materials, University of Illinois, Urbana, Ill.; and L. H. Winkler, metallurgical engineer, Bethlehem Steel Company, Inc.

Future Meetings of Other Societies

American Chemical Society. National Chemical Exposition, September 10–14, 1946, Chicago, Ill.

American Society of Mechanical Engineers. Fall meeting, September 30–October 2, 1946, Boston, Mass.

American Welding Society. Annual meeting, November 17–22, 1946, Atlantic City, N. J.

Electrochemical Society. Fall meeting, October 16–19, 1946, Toronto, Ontario, Canada.

Illuminating Engineering Society. National convention, September 18–21, 1946, Quebec, Quebec, Canada.

Instrument Society of America. Exhibit and conference, September 16–20, 1946, Pittsburgh, Pa.

Iron and Steel Exposition. October 1–4, 1946, Cleveland, Ohio.

National Electrical Contractors Association. Annual meeting, October 14–18, 1946, Atlantic City, N. J.

National Electrical Manufacturers Association. Annual meeting, October 28–November 1, 1946, Atlantic City, N. J.

National Electronics Conference. October 3–5, 1946, Chicago, Ill.

National Exposition of Power and Mechanical Engineering. December 2–7, 1946, New York, N. Y.

Refrigeration Equipment Manufacturers Association. Fourth refrigeration and air conditioning exposition, October 29–November 1, 1946, Cleveland, Ohio.

Television Broadcasters Association, Inc. Second conference and exhibition, October 10–11, 1946, New York, N. Y.

World Conference on Minerals. A three-day world conference on mineral resources originally scheduled to be held in New York, N. Y., September 16–18, in connection with the observance of the 75th anniversary of the American Institute of Mining and Metallurgical Engineers, has been postponed to the week of March 17, 1947. Increased requirements for hotel accommodations for the United Nations made the change in dates necessary. The conference will cover all phases of the present world situation with respect to iron and steel, coal, petroleum, nonferrous metals, and other important industrial minerals. Delegates from every mineral producing country have been invited, and the State Department is disseminating information about the conference through its representatives. Herbert Hoover (HM '29) will be conference chairman, and among those who have accepted invitations are J. A. Krug, Secretary of the Interior; Sir William Fraser, chairman of the Anglo-Iranian Oil Company; Charles M. White, president of Republic Steel Company; and Cornelius F. Kelly, chairman of the Anaconda Copper Mining Company.

Registration by Endorsement. For the benefit of engineers wishing to take advantage of the method of registration by endorsement offered by the National Bureau of Engineering Registration, the address of the bureau is: P. O. Drawer 1404, Carolina Life Building, Columbia, S. C. The work of the bureau was described in the June issue of *Electrical Engineering*, page 294.

SPEE Has New Name. On July 1, 1946, the Society for the Promotion of Engineering Education became the American Society for Engineering Education, according to an announcement received from F. L. Bishop, secretary to the society.

HONORS

Willard Dow Receives Chemical Medal. The Chemical Industry Medal for 1946 has been awarded to Doctor Willard H. Dow, president and chairman of the Dow Chemical Company, Midland, Mich., for "his conspicuous service to applied industry." Doctor Dow also is president of the Ethyl-Dow Chemical Company which extracts bromine from sea water. Under his direction the Dow Company carried out more than 50 wartime projects for the Government. He served on the Chemical Advisory Committee of the Army and Navy Munitions Board and on the Chemical Warfare Service Advisory Board. Doctor Dow commenced his career with the company which his father founded in 1919, the year of his graduation from the University of Michigan. He took over the duties of president and general manager in 1930 and chairman of the board in 1941. Doctor Dow was the recipient of the Chandler Medal of Columbia University in 1943 and of the Gold Medal Award of the American Institute of Chemists in 1944. He holds honorary degrees from Michigan College of Mining and Technology, the University of Michigan, and the Illinois Institute of Technology.

EDUCATION

W. E. Wickenden Announces His Retirement in 1947

At a dinner of the faculty of the Case School of Applied Science, Cleveland, Ohio, on June 16, President William E. Wickenden (F '39) announced his intention to retire from his duties August 31, 1947. Doctor Wickenden became third president of the Case School in September 1929.

In making his announcement, Doctor Wickenden stated: "It is my firm belief that a college president should be a relatively young man who will instinctively look to the future rather than the past and plan with discernment for the needs of an oncoming generation. A new president can benefit greatly by the opportunity to begin his work with the rise of a new economic cycle rather than near its end. Case now has completed a great war chapter in its history. It has renewed its internal organization and has launched an expanding postwar program. It is also in a sound financial condition. A new president should find here an outstanding opportunity

to do creative work and a propitious time to begin."

Commenting on Doctor Wickenden's resignation, Charles C. Bradford, president of the Case Alumni Association, declared that "Every alumnus of Case will regret the resignation of Doctor Wickenden. Under his dynamic leadership, the college has advanced to a position of national prominence in the fields of pure and applied science. With supreme vision, he has laid the foundation for a greater Case in the future.

"Few people realize the many contributions in research and in technical developments that were made to the war effort by Case under Doctor Wickenden's direction. Case will miss its genial president and great leader. He will take with him the sincere appreciation and best wishes of all Case alumni."

Frank A. Quail, president of the board of trustees, stated that Doctor Wickenden's request had been granted with much reluctance and that a committee has been appointed to seek a successor.

Rensselaer Appoints Doctor Crew. William H. Crew, former chairman of the physics department of New York University and wartime assistant director of the United States Office of Scientific Research and Development, Washington, D. C., has been made assistant dean of students at Rensselaer Polytechnic Institute. Professor Crew, who was graduated from the United States Naval Academy in 1922 and who received the doctor of philosophy degree from Johns Hopkins University in 1926, joined the faculty of New York University in 1929. He had been on leave of absence since 1941.

RESEARCH • • • • •

Nuclear Physics Studies Resumed by Westinghouse

Commencement of a program of research in nuclear physics, which is a continuation of the fundamental studies that were abandoned by private companies during the war, has been announced by the Westinghouse Research Laboratories. Doctor W. E. Shoupp, manager of the electronics department, will be in charge of the program. Doctor Shoupp is the co-discoverer of photofission—the splitting of uranium atoms by high-energy gamma rays.

Modernization of the 65-foot-high atom smasher is already in progress, Doctor Shoupp disclosed. Chief among the improvements, designed to make operation easier and more automatic, will be the installation of high speed oil diffusion pumps to exhaust the air from the 35-foot vacuum tube. The pumps, using heated oil mists to drive away air molecules, leave less than one of each billion air molecules in a tank.

Before the war the Westinghouse atom smasher was capable of building up a potential of 4,000,000 volts to hurl electrified particles against a target at speeds between 30,000,000 and 100,000,000 miles an hour.

Corrosion Study at MIT. A new program of instruction and research on corrosion of metals, cause of one of the world's greatest economic losses, has been instituted at Massachusetts Institute of Technology with the appointment of Doctor Herbert H. Uhlig as associate professor in the department of metallurgy to take charge of the project. Hitherto different aspects of the problem have been investigated separately by several departments. Now the resources of all departments concerned will be co-ordinated into a single program. Doctor Uhlig plans a fundamental research program with the study of the nature of metals and metal surfaces as its main objective. The problem will be attacked from an electrochemical viewpoint and is expected to lead to a more logical approach to the selection of corrosion resistant metals and to methods of protection. Doctor Uhlig previously was associated with Rockefeller Institute, Lever Brothers, and the General Electric Company. He is editor-in-chief of the "Corrosion Handbook."

INDUSTRY • • • • •

Trucking Company Installs Radiotelephones

Completion of a two-way radio system for its fleet of more than 1,000 vehicles has been announced by the Willett Company, Chicago, Ill., and by the Raytheon Manufacturing Company which performed the installation.

The two-way radiotelephone system permits a centrally located dispatcher to communicate with any truck in the normal operating area of the company. By radiotelephone, the dispatcher can advise a truck driver immediately of cancellation of a delivery or a new order for a pickup and in deliveries of valuable cargo, the radiotelephone is a deterrent to burglary. The radiotelephone system can be equipped to operate from a concealed foot switch, so that the transmitter is placed on the air. Burglar alarms on the trucks also can be made to actuate the transmitter automatically. Radio-equipped trucks are of civic value as well, as they can immediately report fire, accident, or other emergencies encountered on their routes.

The Willett system operates on 156 to 162 megacycles.

Air-Borne Device Explores for Oil. An air-borne magnetometer, which during the war was used in hunting submarines, now promises to be the fastest means of mapping the underground structure of the most inaccessible ocean, jungle, and mountain regions. Though it was originally developed by the Gulf Oil Corporation for geophysical prospecting, the magnetic detector was perfected in 1941, and the war immediately altered its use from an industrial tool to a weapon. Flown low in blimps and airplanes the instrument gives a continuous magnetic chart of any terrain. By inferring the position of the highly magnetized basement igneous rock, it gives information about the oil-bearing formations lying above the igneous rock. It is the only known method of magnetic mapping over areas where erratic surface influences make ground reading untrustworthy and of magnetic prospecting over water. The instrument is carried in a bomb-like casing trailed beneath the airplane to eliminate magnetic interference.

Refrigeration Industry Standardizes Nomenclature

Formation of ASA Nomenclature Committee B53, sponsored by the American Society of Refrigerating Engineers, has been announced. The committee will provide terms and definitions relating to principles, processes, and equipment in design, manufacture, use, and maintenance in the refrigeration industry. Appropriate symbols also will be provided in instances not covered by existing standards.

The work of the committee has been divided among four subcommittees, namely:

1. Definitions—*Chairman*, R. J. Thompson, sale engineer, Kinetic Chemicals Company.
2. Abbreviations—*Chairman*, Clifford Strock, editor, *Heating and Ventilating*.
3. Letter symbols—*Chairman*, Professor Carl F. Kayan, Columbia University.
4. Graphical symbols—*Chairman*, E. R. Wolfert, Westinghouse Electric Corporation.

Sterling Smith, of the Baker Ice Machine Company, Omaha, Nebr., has been named chairman and M. M. Lawlor of the Worthington Pump and Machinery Company Harrison, N. J., vice-chairman of the committee.

Course on Electric Instruments Prepared by Westinghouse

Designed to give concisely a fundamental knowledge of the construction, operation, and selection of electric measuring instruments, an intensive course including sound slide films, a complete pocket size textbook, and an instructor's manual has been prepared by the Westinghouse Electric Corporation.

Primarily for use by the Westinghouse organization, the course also has been made available to educational institutions, engineering societies, and the engineering departments of all organizations that use electric measuring instruments. Cost of a complete course, based on a class of 20 members is $45. Distribution will be

handled by the industrial relations department, Westinghouse Electric Corporation, 306 Fourth Avenue, Pittsburgh 30, Pa.

Subjects covered in films and lessons are: importance of electrical instruments, the permanent magnet moving coil mechanism, the electrodynamometer mechanism, the stationary coil and moving iron mechanism, the rotating vane mechanism, and the selection and use of electric instruments. It is recommended that the course be given in six one-hour sessions, with each session covering one lesson. An instructor's manual is provided.

Flying Laboratory Equipped by Honeywell. A converted C-47 airplane equipped with electronic instruments designed to measure and record more than 1,000 different functions of flight now is serving as an aeronautical laboratory for the Minneapolis-Honeywell Regulator Company. The airplane contains more than 20 miles of special electric wiring for connecting the electric system to measuring devices which record reactions to the 31 or more automatic control systems now under test. The airplane has a power supply capable of developing more than eight times the electric power of conventional DC-3 airplanes, and the craft is the first to be equipped with a radiant heating system, the latter requiring double walls and windows and a gasoline heater.

Improved Film Aids Television. A new motion picture film which will aid the telecasting of public events within a few hours or even minutes of their occurrence and give improved television images was demonstrated recently by E. I. du Pont de Nemours and Company, Wilmington, Del., manufacturers of the film, and the National Broadcasting Company, New York, N. Y. Newsreel pictures of a parade of the 442d Infantry combat team in Washington, D. C., were flown to New York immediately after the event for televising over station WNBT. To save processing time the new film was used in negative form with a minimum of editing. Use of the negative is possible since the picture is reversed as it passes through each stage of signal amplification in the television system. Therefore, only an odd number of amplification stages is needed to secure a positive representation on the receiving tube.

New Corrosion Protection. A method of protecting the galvanized coating on iron water tanks from too rapid wear and the tank from imperfections in the coating has been developed in connection with the manufacture of the Clark Water Heater by the McGraw Electric Company, Chicago, Ill. By the Clark method, a bar of magnesium is inserted in the center of the tank. Since magnesium is even more active electrically with regard to iron than the zinc coating of the tank, this bar gives protection so long as any magnesium remains. Because the current between the magnesium and the iron is much higher than is needed for protection, a resistance is inserted between the iron and the magnesium and the current consequently lowered to a point where protection is entirely adequate. At the same time the loss of the magnesium is controlled or metered to enable it to last for many years.

Pneumatic Testing Machine. A pneumatically operated fatigue testing machine, which has produced stresses as high as 100,000 pounds per square inch, with no more air being used than that supplied by the average vacuum cleaner, was described at the recent annual meeting of the American Society for Testing Materials in Buffalo, N. Y. Air from two tubes, which may be tuned to any vibrating frequency by varying the length of the air column, strike the sample piece setting it to vibrating. When the air in the tube is adjusted to the same frequency as the test sample, very large and stable amplitudes of vibrations are produced with comparatively small amounts of air. The sample vibrates until it fatigues to the extent that its vibrations are out of phase with those of the tuned air and a break occurs. Current research with the machine indicates that by use of a recording frequency meter, the point of incipient failure may be determined. Brittle materials have shown this point to be very close to that of complete fracture, but in ductile materials it appears long before visible fracture becomes apparent.

Industry Committee Elects Stevenson. H. R. Stevenson of the Detroit Edison Company recently was elected chairman of the Industry Committee on Interior Wiring Design. Mr. Stevenson also was named chairman of the technical subcommittee which soon will commence work on revising the wiring standards for commercial, public, and industrial occupancies. It also was reported at the election meeting that since its release in February, the "Handbook of Residential Wiring Design" (*EE, Feb '45, p 93*) has elicited a response of 185,000 orders. The "Handbook of Farmstead Wiring Design" (*EE, Feb '45, p 93*) is now ready for distribution, and orders for 50,000 copies have been received. A. Carl Bredahl (M '44) of the Westinghouse Electric Corporation, former chairman of the technical subcommittee, was re-elected secretary of the committee.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Australian Member Views England, U. S., and Canada

To the Editor:

I am writing this letter to give a few high lights of my recent trip to England, the United States, and Canada, and some impressions I obtained during the trip, and something of the conditions I have found upon my return to Australia.

My trip started when I left Sydney July 16, 1945, and took six weeks via Panama to England on a troop ship, V-J Day occurring just after we entered the Atlantic Ocean. My first two impressions of England were the cheerfulness of the people considering the ordeal through which they had passed, and secondly, the apparent better health of the children in the poorer districts, due undoubtedly to the very equitable rationing scheme and methods of seeing that the children received whatever good food there was available. During almost 12 weeks I was in England I traveled some 4,000 miles, visited some 50 concerns, including several in Scotland, and left with a greater appreciation than ever of the people.

Another impression I gained was that the people were much more friendly and more keen to help a stranger than they were on my last visit, which undoubtedly was due to the many experiences everyone had had during the war.

In the United States of America and Canada I traveled something over 8,000 miles by rail and visited approximately 60 concerns. I had the expected trouble with hotel accommodation, and a number of rather uncomfortable rail trips, as I was not able always to book the seats too far ahead.

As to my impressions of the United States and Canada, in which I once lived for three years, I found that there are a number of changes, many of which are a direct consequence of the war and are quite abnormal. The population is mixing more than it used to, and I found it much more difficult to determine from the speech of the people what part of the country they hailed from. It appears to me to be all to the good that North and South and East and West should mingle more. Again, in the United States and Toronto, Canada, I cannot speak too highly of the way I was received and treated, and I do not take this all as a compliment to my position or personality, but rather to the

very favorable and wonderful publicity for Australia and Australians which has been given by servicemen who spent time in Australia and have returned to America.

To all my overseas friends I would say that, while we in Australia are essentially British in sympathies, and Britain being our best customer must receive preference where comparable goods are available, nevertheless, so far as conditions in Australia are concerned—the mode of living, the distances to travel, and the variations of climate from North to South—they are much more comparable with those of the United States. In consequence, some United States products, such as motor cars, are more suitable for our purposes than are Engliah ones.

As to conditions in Australia, I am able to confirm that the statement I made in England that the cost of living in Australia was lower and that the English wages were higher, is correct; also my statement in United States that the Australian cost of living is about one third and wages one third those in the United States is correct.

Making a quick and brief survey around the shops of Melbourne on the day of my arrival I was able to confirm that various foods and most essentials are one third the price of those in America under present exchange conditions. The only instance where prices are at all comparable, or may even be higher, is in certain luxury lines which are imported, and such items as motor cars and oil fuel which also are imported. As to what will happen concerning the exchange situation, I cannot see how it will be possible to allow it to continue at the present rate for very long. Even so, we will still have a very great advantage in the cost of living and general over-all production costs. For this reason I believe that Australia has a very great future, particularly if it is possible to obtain any real stability in the industrial field. While it is recognized that our industrial arbitration system has in it room for much improvement, I am satisfied that it is better than anything so far evolved in the United States, Canada, or England.

On the domestic side I find that some clothing is rather short, but owing to our rationing we all will get our share. Some items of food are still not available, even though they are produced in large quantities and normally exported. For example, prunes and rice and arrowroot, which comes from the adjacent Pacific Islands, are also nonprocurable. Meat, butter, sugar, and tea still are rationed. The butter ration is six ounces per week (my United States friends, we do get the six ounces too), tea is two ounces per person per week, while sugar has been increased to two pounds per person per week. Meat is on a basis of value which would be very difficult to give here, but all I can say is that it is three or four times as much as the English ration, but of course that is still a fraction of our prewar meat diet, Australia having been one of the largest meat-eating countries in the world. Though some items of clothing are scarce, knitted wear and several other items have been taken off the rationing list; and, though cotton quality is not very high, nevertheless, there appears to be clothing enough to go around. Altogether I think the Rationing and Price Fixing Departments have done a really good job, even though sometimes we do find the restrictions annoying.

In case this letter should appear too much of a eulogy, perhaps I should include some small criticism.

We here in Australia have suffered criticism from globe-trotting people for many generations, much of it undoubtedly, justifiable, but we do object to the person who spends six weeks or little more in our 3,000,000 square mile country and goes away and writes a book about it. One of the earliest offenders and one of the worst was Foster Frazer. He wrote such rubbish as: "Australia's Songless Birds and Scentless Flowers" and "It is possible to drive a horse in a four-wheeled buggy through any part of the Australian forest."

To my friends in Great Britain I would say that I don't like milk in my tea, and have not spoiled either of the two good beverages by mixing them for at least 25 years. I can say safely that at least 30 per cent of the men of Australia do not mix these two drinks, whatever others they may mix; and secondly the one thing I missed in Britain more than anything was my morning shower, and on the one occasion when I tried a cold plunge bath, I am afraid I was not popular with the hotel maids.

To my American and Canadian friends, please understand that we of the three British Dominions below the Equator are as British as any Englishman, nevertheless, like Scotsmen, do not like to be called English. In other words, I would remind you that there are a good many millions of people who speak the English language unlike the way it is spoken on the American Continent, who are not necessarily English.

I found it a great inconvenience and sometimes a loss of time in contacting many concerns in the United States that the peculiar custom has grown up of omitting to include the telephone number on business letterheads, and sometimes on personal visiting cards. I failed to find any good reason for this practice, and when choice of hotels does not exist, telephone books can be scarce, particularly intercity telephone books.

Finally, I would say that I returned to Australia with increasing confidence for its future and a further conviction that the two requisites to its progress are more people and more capital. I hope to see many from the crowded parts of England and Europe and many of the adventurous souls from the United States also coming here. As to a place for investment, I don't say this is typical, but I noticed the other day that on the ordinary shares of the Goodyear Tire and Rubber Company (Australia), Ltd., which are owned by America, the dividend for last year was 22 per cent.

R. ALAN CROOK (M '44)

(Managing director, Alan Crook Electrical Company, Proprietary, Ltd., St. Leonards, New South Wales, Australia)

Electrical Problem

To the Editor:

In my work I have come across the following problem which lends itself to a rather tricky solution. Though the mathematical solution becomes quite involved, the diagrammatical solution is fairly simple.

When the switch in Figure 1 is opened, determine:

1. The value of R_3 to give maximum rise in line current.
2. The rise in line current.

The solution follows.

In the circuit $I_1+I_3=I_{line}$, or on the vector diagram $\mathbf{AB}+\mathbf{BD}=\mathbf{AD}$.

Point D follows the locus of a circle diagram, so that to I_1 is added semicircle BDE drawn on diameter

$$BE=\frac{E}{X_c}$$

at right angle to AB.

From point A through the center, c, of the semicircle a line is drawn, ACD. If at point D, on the circumference a tangent MM to the semicircle is drawn and a circle, NN, with center at A and radius AD drawn, it is seen from the geometry of the figure line ACD will be the maximum current.

On the figure $AB=E/R_1$ and $CB=E/2X_c$. Therefore,

$$AC=E\sqrt{\frac{1}{R_1^2}+\frac{1}{4X_c^2}}=\frac{E}{2R_1X_c}\sqrt{R_1^2+4X_c^2}$$

Therefore,

$$\text{Maximum } I_{line}=\frac{E}{2X_c}+\frac{E}{2R_1X_c}\sqrt{R_1^2+4X_c^2}$$

$$=\frac{E}{2X_c}\left[1+\frac{\sqrt{R_1^2+4X_c^2}}{R_1}\right]$$

$$\theta=\tan^{-1}\frac{E/2X_c}{E/R_1}=\tan^{-1}\frac{R_1}{2X_c}$$

$$I_3=I_{3x}+jI_{3y}$$

or geometrically

$$\mathbf{BD}=BG+jGD$$
$$=CF+j[BC+FD]$$

Then

$$I_{3x}=\frac{E}{2X_c}\cos\theta$$

and

$$I_{3y}=\frac{E}{2X_c}+\frac{E}{2X_c}\sin\theta=\frac{E}{2X_c}[1+\sin\theta]$$

yielding

$$R_3=\frac{E}{I_3}\frac{I_{3x}}{I_3}$$

With switch closed

$$I_{line}=\sqrt{\left(\frac{E}{R_1}\right)^2+(E/X_c)^2}$$

$$=\frac{E}{R_1X_c}\sqrt{R_1^2+X_c^2}$$

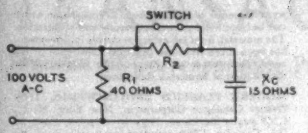


Figure 1. The problem

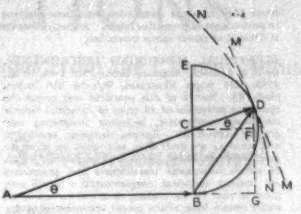


Figure 2. The solution

Using the circuit values:

$E = 100$ volts
$R_1 = 40$ ohms
$X_c = 15$ ohms

$$\text{Maximum } I_{\text{max}} = \frac{100}{30}\left[1+\frac{\sqrt{40^2+4(15)^2}}{40}\right]$$
$$= 7.5 \text{ amperes}$$

$$\theta = \tan^{-1}\frac{40}{30}$$

therefore $\cos\theta = \frac{3}{5}$ and $\sin\theta = \frac{4}{5}$

$$I_{ax} = \frac{100}{30}\frac{3}{5} = 2 \text{ amperes}$$

$$I_{xy} = \frac{100}{30}\left[1+\frac{4}{5}\right] = 6 \text{ amperes}$$

$$I_2 = \sqrt{2^2+6^2} = \sqrt{38}$$

$$R_1 = \frac{100}{\sqrt{38}}\frac{2}{\sqrt{38}} = \frac{100}{19} = 5.24 \text{ ohms}$$

With switch closed

$$I_{\text{max}} = \frac{100}{15\times 40}\sqrt{15^2+40^2} = 7.12 \text{ amperes}$$

Then the rise is 0.38 ampere.

E. NORMAN LURCH (A '45)

(Department of electrical engineering, Manhattan College, New York, N. Y.)

NEW BOOKS . . .

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

PRODUITS RÉSINEUX. By R. Lombard. Preface by J. Duclaux. Dunod, Paris, France, 1946. 315 pages, illustrated, 9 by 5½ inches, paper, 385 francs. A general study of resinous materials of vegetable origin is presented with a thorough treatment of the chemistry of their constituents. Considerable space is devoted to colophony, the common pine resin remaining after turpentine distillation. Its chemistry and applications are covered, and a bibliography on its comparison with other natural resins is included. A brief chapter on methods of analysis of resinous products concludes the book.

PRODUCTION ILLUSTRATION, the Techniques and Applications of Perspective Engineering Drawings. By J. Treacy. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1945. 202 pages, illustrations, diagrams, charts, tables, 9¼ by 11¼ inches, cloth, $4. This book presents the forms and processes of production illustration in simple form including the actual preparation of production illustrations as well as a discussion of why, when, and where production illustration is of use in industrial production. The book is illustrated profusely with examples of actual production drawings.

RUSSIAN-ENGLISH SCIENTIFIC-TECHNICAL DICTIONARY, compiled and edited by A. Bray. International Universities Press, 227 West 13th St., New York, N. Y., 1945. 551 pages, 9½ by 6 inches, cloth, $10. The scope of this dictionary is indicated by the types of words included: basic terminology of fundamental fields such as mathematics, mechanics, physics, and chemistry; words and expressions for all the main technical fields likely not to be found in a general dictionary; and terms pertaining to new fields of science and industry.

STEELWAYS OF NEW ENGLAND. By A. F. Harlow. Creative Age Press, New York, N. Y., 1946. 461 pages, illustrated, 8½ by 5½ inches, cloth, $3.50. First of a projected series covering the American railroads, this book presents a detailed history of the many roads, which occupied the New England scene. Beginning with the first horse-operated line out of Quincy, Mass., in 1826, the author depicts the struggles, successes, and failures incidental to the growth of the present-day network which serves the New England States. A 13-page bibliography and a detailed index add to the value of the book.

ATOMIC ENERGY in WAR and PEACE. By G. G. Hawley and S. W. Leifson. Reinhold Publishing Corporation, New York, N. Y., 1945. 211 pages, illustrated, diagrams, tables, 7¾ by 5 inches, cloth, $2.50. The first part of this book discusses atoms, neutrons, energy transformations, combustion, explosions, radioactivity, transmutation, nuclear fission, and other subjects of fundamental importance. The second part, based on the official report of the atomic bomb project, gives the story of this tremendous job, the obstacles to be surmounted, and the means by which it was done. A concluding section discusses future military and industrial applications of atomic energy in the light of present knowledge.

RÉSINES VINYLIQUES. By H. Gibello. Preface by J. Duclaux. Dunod, Paris, France, 1946. 222 pages, illustrated, 9 by 5½ inches, paper, 260 francs. The theory and practice of the fabrication and polymerization of vinyl resins are covered in the first three chapters. The chemical derivatives of the polymers are discussed. Two chapters are devoted to industrial applications of vinyl compounds, one from the viewpoint of the field of use, the other by considering the various resins individually. The qualitative and quantitative analysis of vinyl resins is treated briefly.

RUBBER IN ENGINEERING. Prepared under the direction of the Controller of Chemical Research of the British Ministry of Supply and the Directors of Scientific Research of the Ministry of Aircraft Production and the Admiralty on the Basis of Research carried out by the Imperial Chemical Industries, Ltd. Chemical Publishing Company, Brooklyn, N. Y., 1946. 267 pages, illustrated, 8¾ by 5½ inches, cloth, $5.50. Part I, describing the rubber-like state, and part II, discussing the general properties of rubber, furnish engineers with a general survey of the information available on the theoretical aspects of the subject. Part III provides useful information on the compatibility and incompatibility of rubber properties in their relation to practical use, covers the bonding of rubber to metal, and discusses other aspects of rubber technology. Part IV deals at some length with the principles of the design of rubber engineering components for shock absorption, vibration insulation, and the like.

MEDICINE IN INDUSTRY. By B. J. Stern. Commonwealth Fund, New York, N. Y., 1946. 209 pages, tables, 8½ by 5¼ inches, cloth, $1.50. The author traces broadly the social, economic, legal, and professional setting within which industrial medicine has progressed, and discusses the development of knowledge which enables industrial physicians to cope with many diseases affected by occupations. Data are presented on the rates of industrial disability and the limited extent or preventive services. Recent developments in health and insurance programs are dealt with, the problems of the handicapped in industry are considered, and the relationships between industrial physician and general practitioner are discussed.

SEQUENTIAL ANALYSIS IN INSPECTION AND EXPERIMENTATION. Revised and enlarged edition. Prepared by the statistical research group, Columbia University, for the Applied Mathematics Panel, National Defense Research Committee, Office of Scientific Research and Development. Columbia University Press, New York, N. Y., 1945. Paged in sections, illustrated, 11½ by 10 inches, lithoprinted, loose leaf, fabrikoid binder, $6.25. Section I of this work discusses the general theory of the method as applied to inspection and experimentation. Sections II to VI inclusive describe the practical operation of the system under varying conditions and for various purposes. Some of the properties and fundamental mathematical principles of sequential analysis are explained in the appendixes which occupy the last section. The several sections are bound in separate pamphlet form and contained in a ring binder for easier separate use.

TABLES OF FUNCTIONS WITH FORMULAE AND CURVES (Funktionentafeln mit Formeln und Kurven). By E. Jahnke und F. Emde. Fourth edition. Dover Publications, New York, N. Y., 1945. 306 pages+76 pages, illustrated, 9 by 5½ inches, cloth, $3.75. This collection of tables again has been reprinted, with many errors corrected and a supplementary bibliography. These changes increase the value of the book already great as the most comprehensive in its field.

TIME STUDY AND MOTION ECONOMY. By R. L. Morrow. Ronald Press Company, New York, N. Y., 1946. 338 pages, illustrated, 9½ by 6 inches, cloth, $5. All procedures described in this book, with the exception of the new synthetic leveling, have been used regularly in practice. The author describes ways to study operations, take observations, and compute all necessary data. Charts, tables, and diagrams are used extensively to illustrate the methods and the kinds of records discussed in the text. The book is designed for the small as well as for the large plant.

PLANNING FOR JOBS. Edited by L. Fitch and H. Taylor. Blakiston Company, Philadelphia, Pa., and Toronto, Ontario, Canada, 1946. 463 pages, tables, 8¼ by 5¼ inches, cloth, $3.75. The plans and suggestions presented in this book were selected from several thousand submitted essays and cover a wide range of opinions and points of view. The material is grouped under several headings: measures to promote private investment, including tax reforms and the abolishing of restrictive practices; measures to promote consumption, including tax reforms and consumer subsidies; fiscal programs and momentary reforms, including public works and market programs; and measures dealing with the supply of labor and the labor market, including wage and labor union reforms and work sharing proposals. The object is to indicate the principal trends of public thinking.

NEW CAREERS IN INDUSTRY. By J. M. Amiss and E. Sherman. McGraw-Hill Book Company, Whittlesey House Division, New York, N. Y., and London, England, 1946. 227 pages, illustrated, 8¼ by 5½ inches, cloth, $2.50. The main types of jobs available in industry are discussed from several viewpoints. Necessarily, information is given about duties, working conditions, wages, and qualifications. Additionally, the authors emphasize the importance of the individual job, its place in the total pattern of industry, and opportunities for advancement. The field is covered from the machine operator to the salesman,

from the supervisor of mechanical operations to the supervisor of personnel and labor relations. Suggestions also are given for planning for the necessary educational training and for the evaluation of one's own qualifications.

JOB EVALUATION METHODS. By C. W. Lytle. Ronald Press Company, New York, N. Y., 1946. 329 pages, illustrations, 9½ by 6 inches, cloth, $6. The author presents an analytic approach to the subject. The procedure of job analysis and evaluation is separated into functional steps as indicated by the chapter headings, in order to compare and select methods and characteristics to fit any given set of conditions. The application of evaluation to office and supervisory positions is considered, and there is a special chapter on merit rating.

EXECUTIVE IN ACTION. By M. E. Dimock. Harper and Brothers, New York, N. Y., and London, England, 1945. 276 pages, 8½ by 5½ inches, cloth, $3. From the executive's viewpoint this book discusses the day by day activities of an executive, how he functions in a new organization, in general organization policies, in financial planning, personnel control and other phases of business. It attempts to show that there is more in common between business and government than there is of difference. The author draws on his own experience, largely in governmental positions, for examples to illustrate the practices discussed.

ELECTRIC CIRCUITS AND MACHINES. By E. C. Lister. McGraw-Hill Book Company, New York, N. Y., and London, England, 1945. 358 pages, illustrated, 8½ by 5¼ inches, cloth, $3.50. This text, prepared for a brief course offered in the specialized training program at Iowa State College during the years 1942-44, covers the fundamentals of electricity with which the practical man must be familiar. The treatment is as nonmathematical as is practicable.

TÉLÉTRANSMISSIONS PAR ONDES PORTEUSES. By A. Chevallier. Preface by E. Mercier. Dunod, Paris, France, 1946. 111 pages, illustrated, 10 by 6¾ inches, paper, 390 francs. This book covers the theory and practice of teletransmission by carrier waves in high voltage networks. Connections, methods of modulation, radiation from high voltage lines, transmitting and receiving equipment, wave ranges, and filters are some of the topics covered. Separate chapters are devoted to telephony, selective protection of high voltage lines, and impulse frequency telemetering.

LES VIBRATIONS SUR LES AVIONS. By M. Berthaume. Preface by M. Vernisse. Dunod, Paris, France, 1946. 79 pages, illustrated, 10 by 6¾ inches, paper, 275 francs. Beginning with a theoretical discussion of the characteristics of vibration in airplanes, this book proceeds to a practical treatment of the necessary calculations and methods of testing, with numerical examples. Information is given on methods for reducing these vibrations, with specific remedies for specified cases.

LUMINOUS TUBE LIGHTING. By H. A. Miller. Chemical Publishing Company, Brooklyn, N. Y., 1946. 143 pages, illustrated, 8¾ by 5½ inches, cloth, $3.50. The underlying principles of the luminous tube are explained, the materials and equipment involved in their manufacture are described, and the discharge tube light sources are discussed. Both low and high pressure tubes are considered, and a separate chapter covers neon signs. A collection of technical data is included.

ELECTRONIC EQUIPMENT. By R. C. Walker. Chemical Publishing Company, Brooklyn, N. Y., 1945. 393 pages, illustrated, 8½ by 5¼ inches, cloth, $6. Specific information is given on the various applications of electronic devices, with many illustrative examples outside the field of telecommunication. The book constitutes a simple introduction of the main sections of the subject of electronics to practical engineers, mechanics, and the like.

ELECTRICAL PROTECTIVE EQUIPMENT AND POWER-FACTOR CORRECTION. By E. S. Lincoln. Essential Books, New York, N. Y., 1945. 242 pages, illustrated, 8½ by 5½ inches, cloth, $3. This book presents the fundamentals of electric circuit protection by means of fuses and circuit breakers against overloads, reverse currents under voltage, and overvoltage. The equipment is described in detail, including fire protection and fire fighting equipment. The material is based on the provisions of the National Electric Code and the National Electrical Manufacturers Association definitions applying to protection and protective relays. A special chapter is devoted to power factor correction.

ELECTRICAL MEASURING INSTRUMENTS. By E. S. Lincoln. Essential Books, New York, N. Y., 1945. 284 pages, illustrated, 8½ by 5½ inches, cloth, $3. Part I of this practical text covers the operating principles of all types of industrial electric measuring instruments, including integrating and graphic instruments. Ranges, damping, sensitivity, and accuracy are dealt with, and tables are given for quick reference in the selection of instruments. Part II covers instrument transformers and procedures for making electrical measurements. Details are given in part III for making electrical surveys of an entire system from which proper operation of equipment and useful economies may be determined.

ELECTRIC MOTORS AND GENERATORS. By E. S. Lincoln. Essential Books, New York, N. Y., 1945. 381 pages, illustrated, 8½ by 5½ inches, cloth, $3. This practical volume describes all kinds of d-c and a-c motors and generators, with instructions for installation and operation. Tables are provided showing complete standardization of motor manufacture and use. A final chapter covers a variety of related drives: belting, gears, chain drives, variable speed transmission, couplings, and clutches.

EINLEITUNG IN DIE MENGENLEHRE. By A. Fraenkel. Third revision and enlarged edition, 1946. 424 pages, illustrated, 8½ by 5½ inches, cloth, $4. The first three chapters of this standard German work on the theory of aggregates cover the usual material: fundamentals and cardinal numbers; operations with cardinal numbers; order types and order numbers. The fourth chapter deals with attacks on the fundamentals and their consequences. The last chapter discusses the axiomatic structure of the theory of sets and the axiomatic method. There is a long bibliography.

DICTIONARY OF AERONAUTICS. By E. B. French. Mentzer, Bush and Company, Chicago, Ill., 1945. 129 pages, illustrated, 8½ by 5½ inches, cloth, 75 cents. Words and phrases in the field of aviation and aeronautical engineering are defined in a concise manner. The illustrations are designed to identify and relate a number of terms as a group. Separate glossaries are provided for aerological and navigational terms.

DESCRIPTIVE GEOMETRY. By E. F. Watts and J. T. Rule. Prentice-Hall, Inc., New York, N. Y., 1946. 301 pages, illustrated, 9½ by 6 inches, cloth, $3. The theory of descriptive geometry is developed fully as a basis for the solving of engineering problems by graphical methods. Separate chapters are appended, dealing with precision in drawing, properties of plane figures, and stereoscopic drawing. Problems accompany each chapter to illustrate in a practical manner the material discussed.

ANALYTICAL GEOMETRY AND CALCULUS. By H. B. Phillips. Addison-Wesley Press, Kendall Square Building, Cambridge, Mass., 1942 (1946 printing). 457 pages plus 21 pages of answers to problems and 47 pages of supplementary problems; diagrams, 9½ by 6 inches, cloth, $5. The object of this text is to provide a course in analytical geometry and calculus for students of science and engineering. Certain fundamental topics in analysis needed for the logical development of calculus are discussed in the first chapter. An elementary treatment of vector analysis and functions of a complex variable is included for work in mechanics and for the analysis of various physical fields.

PRACTICAL SALES MANAGEMENT. By H. Simmons. Prentice-Hall, Inc., New York, N. Y., 1946. 427 pages, illustrated, 9½ by 6 inches, cloth, $5. Modern sales management fundamentals, including the requirements for, and the duties of, a sales manager, are discussed in section I. Section II deals with the selecting, training, and handling of salesmen. Visual selling aids, such as sales manuals and catalogues, are described in section III. The fourth section covers modern research in markets, products, consumers, and sales analysis. Section V includes: sales meetings, selective selling, direct mail advertising, and public speaking.

SUPERVISING PEOPLE. By G. D. Halsey. Harper and Brothers, New York, N. Y., and London, 1946. 233 pages, tables, 8½ by 5¼ inches, cloth, $3. For the use of those who are directly in charge of working groups, the author presents a simple, straightforward statement of all the phases of supervision which can be improved by systematic study and application. The material, from job rating to morale improvement, has been taken from the practical experience of the author and others and gives specific suggestions for the solution of numerous difficulties.

MODERN PLASTICS ENCYCLOPEDIA, 1946. Plastics Catalogue Corporation, New York, N. Y., 1,389 pages, illustrated, 11¼ by 8 inches, cloth, $6 ($7, Canada). This standard compendium of information on plastics commences with a review of recent progress. Methods of identifying and testing plastics are described, the varieties are discussed at length, and their qualities are considered from a practical viewpoint. Other sections deal with engineering design; methods of molding, extruding and casting; fabricating, finishing and assembling; machinery and equipment; laminates, plywood, and vulcanized fiber; coatings; and synthetics and rubber-like plastics.

MODERN PLASTICS. By H. Barron. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1945. 680 pages, illustrated, 8½ by 5½ inches, cloth, $7.50. The introduction discusses raw materials and the polymerization process. The succeeding parts deal respectively with: thermosetting resins and their plastics; cellulose plastics; vinyl plastics; other leading plastics, including casein; some important aspects of plastics, such as the use of high-frequency heating and physical testing methods. Processes and plastics are closely associated, as: molding and phenolics; injection molding and cellulose acetate; extrusion and polyvinyl chloride; fibers and nylon.

NATURAL COLOR PROCESSES. By C. E. Dunn. Fourth edition. American Photographic Publishing Company, Boston, Mass., 1945. 232 pages, illustrated, 8 by 5¼ inches, cloth, $3. Written for the professional and advanced photographer, this book gives detailed information for the making of photographs in color by both the subtractive or additive methods. The author not only covers thoroughly the manipulation of films and filters and the matter of exposure calculations but also gives detailed instructions on the mixing and use of all necessary chemicals—developers, fixers, and so forth. There is an introductory chapter on the theory of simple color analysis.

NATURE OF PATENTABLE INVENTION. By J. E. R. Hayes. Addison-Wesley Press, Cambridge 42, Mass., 1945. 183 pages, 9¼ by 6 inches, cloth, $3. The author first discusses in considerable detail the concept of invention as a mental process. He then takes up the various phrases such as "new and useful result" and "addition to the sum of knowledge" by which the validity of an invention is tested and explains their interpretation. Other sections cover the analysis of ideas, tests for invention, and identification of results. The allowability and the proper expression of claims are dealt with. Throughout the book direct quotations from cases and judgments are used extensively to illustrate the points involved.

PAMPHLETS • • •

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

As the Automobile Comes Back. Publication GED-1104. General Electric Company, Schenectady, N. Y., 27 pages.

The Solar System. New company magazine of the Solar Manufacturing Corporation, 285 Madison Avenue, New York 17, N. Y., which will be issued six times a year.

How to Use One Bank of Transformers to Supply Two Different Loads. By O. T. Farry, Wagner Electric Corporation, 6400 Plymouth Avenue, Saint Louis, Mo., 11 pages, no charge.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Parallel Circuits in Servomechanisms

H. TYLER MARCY
ASSOCIATE AIEE

AN excellent way to describe a servomechanism is to picture it as a device which acts with power on the difference, or error, between a desired quantity and an actual quantity. It acts in such a way as,

1. To make the error approximate zero in the steady state.
2. To limit peak errors and the error-time integral when the output quantity is following a typical random input quantity.
3. To recover from sudden disturbances with adequate speed of response and degree of stability.

A block diagram of a group of components is illustrated in Figure 1 in which the foregoing interpretation is very powerful. Much has been written on the analysis and synthesis of such systems. Several recently published or released works have described powerful analytical tools used in the design of linear servomechanisms of this type.[1-4,7,8]

This paper deals in particular with a class of servomechanisms which has not received adequate treatment thus far. Many servomechanisms, as in Figure 2, can be described accurately only when a component is included in the feed-back path. At times this is desired, and compensating devices are used to aid the performance of the servomechanism. At other times, undesirable characteristics of the measuring instruments introduce delay in the transmission of signals back to a point where they are to be compared with the desired quantity. The signals then used to excite the control amplifier are no longer the error between desired and actual quantities.

In cases where there is a modification of the controlled quantity previous to comparison with the desired quantity, no place exists in the circuit where the actual error can be measured. This is most likely to be true when the servomechanism is not in steady-state operation. The ratio of output to error as a function of frequency when the input is varying sinusoidally is, in these cases, not a simple function of any one of the components or any of the components in cascade. This will be developed mathematically as a part of the linear treatment of servomechanisms of the type represented in Figure 2.

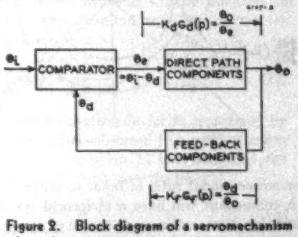


Figure 2. Block diagram of a servomechanism where the components in the direct circuit are paralleled by components in a feed-back circuit

General Analytical Techniques

A mathematical treatment of a dynamic system as complicated as a servomechanism is difficult on the basis of classical mathematics. The differential operator p is used here to represent an operator which will be replaced by $j\omega$ when the steady-state sinusoidal characteristics of the system are to be considered, or by d/dt when the differential equations are to be considered.

The general analytical techniques described here are, basically, simple extensions of previous work.[1,2] In electric network theory, the consideration of all circuits on the basis of impedance characteristics to the exclusion of admittance characteristics would be foolish. Similarly in a study of servomechanisms it is often desirable to work with component or system functions which are ratios of input to output instead of their reciprocals.

Components of servomechanisms (such as amplifiers, thermocouples, tachometers, and motors) can be considered as analogous to a four terminal network whose input and output are related by a differential equation describing its behavior. In this paper a system function will be defined as a nondimensional ratio of output to input. A component will have a system function, and a combination of components will have a system function. It is, therefore, necessary to describe carefully what a given system function includes. It is also necessary to describe the operator used in expressing the system function. If the operator is a pure imaginary frequency, then a ratio of θ_o to θ_i will be written

$$\frac{\theta_o}{\theta_i}(j\omega)$$

The more general operator p is implied by the simple expression θ_o/θ_i, instead of always writing $\theta_o(p)/\theta_i(p)$. Similarly $\theta_i(p) - \theta_o(p)$ will be written $\theta_i - \theta_o$.

A reciprocal system function will be a

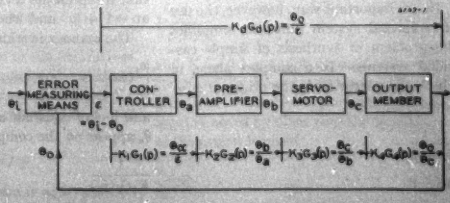


Figure 1. Block diagram of a servomechanism where the components may be considered as elements in a cascade circuit

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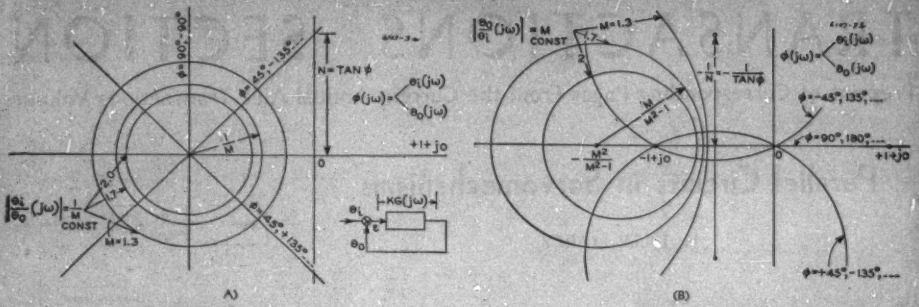


Figure 3. Loci of constant magnitude of the ratio of the output quantity to the input quantity of a servomechanism and loci of constant phase angle between the output quantity and the input quantity of a servomechanism as they appear on two complex planes

A. Plane of $1/KG(j\omega)$. A complex plane where the radius vector is the complex ratio of the error of the servomechanism to the output quantity

B. Plane of $KG(j\omega)$. A complex plane where the radius vector is the complex ratio of the output quantity to the error of the servomechanism

nondimensional ratio of input to output. A component will have a reciprocal system function, and a combination of components will have a reciprocal system function.

The use of reciprocal system functions allows a separation of the component characteristics not otherwise realizable, which leads to greater simplicity of analytical treatment. With reference to Figure 1

$$\frac{\theta_o}{\epsilon}(j\omega) = K_d G_d(j\omega) = K_1 G_1(j\omega) K_2 G_2(j\omega) \times K_3 G_3(j\omega) K_4 G_4(j\omega) \quad (1)$$

and

$$\frac{\theta_o}{\theta_i}(j\omega) = \frac{K_d G_d(j\omega)}{1 + K_d G_d(j\omega)} \quad (2)$$

Inversion of equation 1 leads to

$$\frac{\epsilon}{\theta_o}(j\omega) = \frac{1}{K_d G_d(j\omega)} \quad (3)$$

and inversion of equation 2 leads to

$$\frac{\theta_i}{\theta_o}(j\omega) = 1 + \frac{1}{K_d G_d(j\omega)} \quad (4)$$

and demonstrates that the system may be studied by a treatment of the function $K_d G_d(j\omega)$, or by a treatment of the reciprocal function

$$\frac{1}{K_d G_d(j\omega)}$$

It does not matter which technique is used, because the effect of any one component, for instance $K_1 G_1(j\omega)$, may be studied by a vector product manipulation on a polar plot.

In one important way, however, the use of reciprocal system functions simplifies the problem of synthesis of simple cascaded systems. In a complex plane, in which the vector from the origin at $\omega = \omega_1$ is

$$\frac{1}{K_d G_d(j\omega_1)}$$

loci for

$$\left|\frac{\theta_i}{\theta_o}(j\omega)\right| = \text{constant}$$

are circles, concentric about the $-1 + j0$ point with a radius equal to the magnitude. Loci of constant angle between input and output are straight lines which pass through the $-1 + j0$ point and a point on the imaginary axis equal to the tangent of the angle. These loci are shown in Figure 3, where they may be contrasted with similar loci as they appear on a plane where the vector from the origin at $\omega = \omega_1$ is $K_d G_d(j\omega_1)$.

A simple demonstration of the nature of the loci of constant

$$\left|\frac{\theta_i}{\theta_o}(j\omega)\right|$$

is to set the radius vector

$$\frac{1}{K_d G_d(j\omega)} = R + jX$$

and find the analytical geometric equation for constant

$$\left|\frac{\theta_i}{\theta_o}(j\omega)\right|$$

Substituting in equation 4

$$\frac{\theta_i}{\theta_o}(j\omega) = 1 + R + jX \quad (5)$$

from which

$$\left|\frac{\theta_i}{\theta_o}(j\omega)\right| = \sqrt{(R+1)^2 + X^2} = \frac{1}{M} \quad (6)$$

where the constant M has been defined so as to be consistent with Hall.[1,2] Equation 6 represents a circle whose center is at $-1 + jO$ and whose radius is $1/M$.

The manner in which loci of constant

$$\left|\frac{\theta_i}{\theta_o}(j\omega)\right|$$

and loci of constant angle between θ_i and θ_o appear on the complex plane of

$$\frac{1}{K_d G_d(j\omega)}$$

is important only when these loci are used as design criteria for the servomechanism. In design work the degree of resonance often is limited by specifying a maximum allowable value of M. In terms of the degree of stability of servomechanism transient response this is a rough approximation at best. This is unfortunate because specifications for the speed of response and degree of stability of servomechanisms usually are given in terms of their transient response.

The transient response is related mathematically to the frequency response by the Fourier integral.[3] A perhaps oversimplified interpretation of this relationship is used in specifications of servomechanisms. Such specifications limit the amplification, by resonance effects, of the input and demand a sizable output magnitude at high frequencies. For complicated systems, however, this gives the designer something tangible toward which to work, as well as a good approximate prediction.

The use of the complex plane of

$$\frac{1}{K_d G_d(j\omega)}$$

permits a quick determination of resonance by noting the proximity of the locus to the $-1 + j0$ point. This advantage is, of course, not fundamental. It

is apparent in the solution of numerical problems.

To return to the more complicated system represented in Figure 2: the ratio of output to input is

$$\frac{\theta_o}{\theta_i}(j\omega) = \frac{K_d G_d(j\omega)}{1 + K_d G_d(j\omega) K_f G_f(j\omega)} \tag{7}$$

and the ratio of output to error (defined as $\theta_i - \theta_o$) is

$$\frac{\theta_o}{\epsilon}(j\omega) = \frac{K_d G_d(j\omega)}{1 + K_d G_d(j\omega) K_f G_f(j\omega) - K_d G_d(j\omega)} \tag{8}$$

This is a hopeless tangle to unscramble when an alteration in either $K_d G_d(j\omega)$ or $K_f G_f(j\omega)$ is needed. However the inversion of equation 7 leads to

$$\frac{\theta_i}{\theta_o}(j\omega) = \frac{1}{K_d G_d(j\omega)} + K_f G_f(j\omega) \tag{9}$$

and the inversion of equation 8 leads to

$$\frac{\epsilon}{\theta_o}(j\omega) = \frac{1}{K_d G_d(j\omega)} + K_f G_f(j\omega) - 1 \tag{10}$$

Both equation 9 and equation 10 make possible a separation of the frequency characteristics of the two essential components in the system. Equation 9 and equation 10 indicate a vector addition of the characteristics of the components. The result is obtained with comparative ease and leads quickly to a qualitative idea of the effect of a change in one or the other of the two parallel components.

It would seem from examination of equation 9 and equation 10 that the ratio

$$\frac{\theta_i}{\theta_o}(j\omega)$$

might be plotted instead of

$$\frac{\epsilon}{\theta_o}(j\omega)$$

since the criteria of resonance concerns

$$\frac{\theta_i}{\theta_o}(j\omega)$$

directly. If this is done then loci of constant

$$\left|\frac{\theta_i}{\theta_o}(j\omega)\right|$$

are obviously circles about the origin.

When problems are actually being solved, it often will be convenient to plot on the same sheet of paper a locus of

$$\frac{\epsilon}{\theta_o}(j\omega)$$

and a locus of

$$\frac{\theta_i}{\theta_o}(j\omega)$$

With reference to equation 9,

$$\frac{1}{K_d G_d(j\omega)}$$

may be plotted as the radius vector, and the resonance of the system may be studied by considering the locus to be

$$\frac{\epsilon}{\theta_o}(j\omega)$$

where $K_f G_f(j\omega)$ is always unity. For this purpose circles may be constructed about the $-1+j0$ point. Then, on the same sheet of paper a locus of $K_f G_f(j\omega)$ may be added vectorially to the locus of

$$\frac{1}{K_d G_d(j\omega)}$$

The resulting locus has a radius vector which is

$$\frac{\theta_i}{\theta_o}(j\omega)$$

and the resonance of the final system may be studied by constructing circles of radius

$$\left|\frac{\theta_i}{\theta_o}(j\omega)\right|$$

about the origin.

Time Delays in Measuring Output

In order to control a process with a servomechanism, it is necessary to measure the output quantity. The accuracy with which the measurement is made, both statically and dynamically, is in large part indicative of the success of the controller. Unfortunately many measurements are made, for one reason or another, with equipment that responds to a sudden input with a time delay. The response delay may be either a characteristic of the measuring instrument or a characteristic of some smoothing circuit that is used.

As an illustrative problem, to show how the effects of a time delay in error measurement may be treated, a system will be discussed where the direct circuit, including control amplifier and process, is characterized by the system function

$$K_d G_d(p) = \frac{K_d}{p(T_d p + 1)} \tag{11}$$

Equation 11 is representative of a cascaded control amplifier sensitive only to the input to it (and not to the derivatives or integrals of that input) and a process characterized by a characteristic time, T_d. Such a system is described in Figure 7 where

$K_d = K_{ea} K_m / f$ and $T_d = J/f$

This much of the system is equivalent to the type I controller of reference 1 in which the ratio of the static stiffness K to the output damping, f, is K_d, or the velocity-error constant, and the ratio of the output inertia, J, to output damping, f, is T_d.

The output measuring device of the illustrative problem will be assumed to have a response indicated by the transfer function,

$$K_f G_f(p) = \frac{1}{T_f p + 1} \tag{12}$$

If the measuring device is considered by itself and is subjected to a sudden input, X_i, then equation 12 indicates that the output, X_o, will have the form

$$X_o = X_i\left(1 - e^{\frac{-t}{T_f}}\right) \tag{13}$$

Before equation 11 and equation 12 are inserted in equation 9 and equation 10 to study the characteristics of the servomechanism, it is desirable to make one change of variable. If $T_d p$ is replaced by λ; the ratio T_f/T_d defined as A; and the product $K_d T_d$ defined as B, then the problem can be generalized, so that the solution will apply to any numerical value of T_d. Equation 11 then may be rewritten as

$$K_d G_d(\lambda) = \frac{B}{\lambda(\lambda + 1)} \tag{14}$$

and equation 12 may be rewritten as

$$K_f G_f(\lambda) = \frac{1}{A\lambda + 1} \tag{15}$$

The servomechanism characteristics then are determined by a substitution in equation 9 and equation 10. A nondimensional frequency variable is introduced when the operator λ is replaced by ju

$$\frac{\theta_i}{\theta_o}(ju) = \frac{ju(ju+1)}{B} + \frac{1}{jAu+1} \tag{16}$$

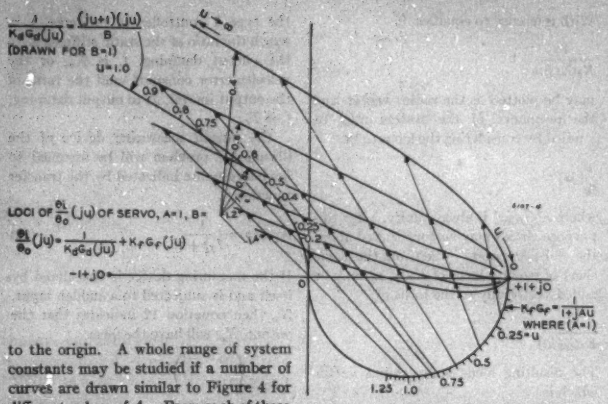
$$\frac{\epsilon}{\theta_o}(ju) = \frac{ju(ju+1)}{B} + \frac{1}{jAu-1} - 1 \tag{17}$$

The effect of change of gain factor B for a given ratio A is illustrated in Figure 4 by a graphical construction of the problem, based on the frequency loci. As illustrated, the functions

$$\frac{1}{K_d G_d(ju)}$$

and $K_f G_f(ju)$ are plotted separately and combined by vector addition. The degree of resonance for a particular adjustment is noted by observing the proximity of the proper locus of

$$\frac{\theta_i}{\theta_o}(ju)$$



to the origin. A whole range of system constants may be studied if a number of curves are drawn similar to Figure 4 for different values of A. From each of these plots a secondary group of curves may be made relating the resonant frequency and degree of resonance

$$\left(\text{minimum value of } \left|\frac{\theta_1}{\theta_0}(j\omega)\right|\right)$$

to the parameter being varied. Finally the data may be translated to the form shown in Figure 5, where lines of constant

$$\left|\frac{\theta_1}{\theta_0}(j\omega)\right|_{\text{minimum}}$$

and lines of constant resonant frequency are plotted as functions of A and B.

The process of examining the effect of change of a system parameter over a range is a laborious process. This is true to different degrees depending on the analytical technique used. Most often the analysis would not be carried so far as the one illustrated. Generally, the nature of the particular problem fixes a number of the parameters, and the problem is reduced in complexity. Quite often, too, the apparatus being considered is at hand for experimental study, and the analysis is used simply as an aid in visualizing the trend that should be observed following a change in the system.

For the problem being discussed it is practical to make a study of the transient response of the system, as well as a study of the frequency response. If the general operator λ is used instead of $j\mu$ and equation 16 is combined and inverted, then

$$\frac{\theta_0(\lambda)}{\theta_i(\lambda)}=\frac{B(A\lambda+1)}{\lambda(\lambda+1)(A\lambda+1)+B}=\frac{B\left(\lambda+\frac{1}{A}\right)}{\lambda^3+\frac{A+1}{A}\lambda^2+\frac{1}{A}\lambda+\frac{B}{A}} \quad (18)$$

The denominator of the right hand side of equation 18 is the characteristic equation of the system when set equal to zero. The roots of the characteristic equation are indicative of the transient response, as has been discussed often in articles of servomechanisms.[1]

Figure 4. Loci for a proportional servomechanism with a time delay in the feed-back circuit to show the effect of change in direct circuit gain for the case of equal characteristic times in direct and feed-back circuits

The characteristic equation for the problem being discussed is

$$\lambda^3+\frac{A+1}{A}\lambda^2+\frac{1}{A}\lambda+\frac{B}{A}=0 \quad (19)$$

which may be factored into the form

$$(\lambda+\alpha)(\lambda^2+2\zeta\mu_n\lambda+\mu_n^2)=0 \quad (20)$$

for particular values of A and B. The undamped natural frequency, μ_n, and the exponential decay constant, α, have been nondimensionalized by the use of the operator λ instead of the operator p. For a particular value of T_d the exponential characteristic time is T_d/α seconds and the undamped natural frequency of the quadratic root, ω_n, is μ_n/T_d radians per second. The damping ratio ζ, defined as the ratio of actual to critical damping of the quadratic factor, is already a nondimensional factor and does not change in value with the reversion of the problem to one of particular values for the process characteristic time T_d and measuring instrument characteristic time T_f.

If a number of solutions of equation 20 are made for several values of A when B is constant, then for the same values of A when B is constant at another value, a series of curves may be drawn which represent α, ζ, and μ_n as a function of A when B is constant. Finally the solution may be redrawn as shown in Figure 6 where lines of constant α, ζ, and μ_n are plotted as a function of A and B. This figure demonstrates immediately the results that will be obtained for a particular adjustment of parameters. There is, however, an omission, in that the magnitude of the two modes of recovery are not compared, which is not serious because it is necessary to admit at the outset, that, unless every system parameter is known

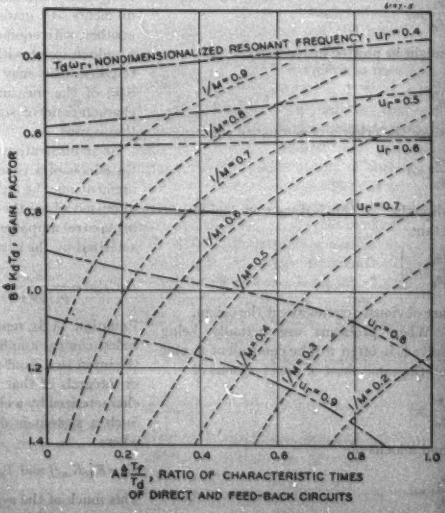


Figure 5. Resonant frequency and degree of resonance, $\left|\frac{\theta_1}{\theta_0}(j\omega)\right|_{\min}=\frac{1}{M}$, as a function of nondimensionalized system parameters of a proportional servomechanism with a time delay in the feed-back circuit

exactly and complete solutions are made for each adjustment, there will have to be a final experimental adjustment of the system. The purpose of the analysis as used in practice is to determine the approximate correct adjustment of the system and to indicate the direction implied by a proposed change of parameter values.

Because the solution to the characteristic equation of the illustrative problem can be presented fairly readily in the form of Figure 6, it is possible in this case to compare the criteria for servomechanism frequency response with criteria for transient response over a range of system adjustment by a comparison of Figures 5 and 6.

An empirical figure of merit for the design of servomechanisms by use of frequency response data has been to limit approximately the degree of resonance so that

$$M_{max} = \left|\frac{\theta_o}{\theta_i}(j\omega)\right|_{max} = 1.5^*$$

or

$$\frac{1}{M_{max}} = \left|\frac{\theta_i}{\theta_o}(j\omega)\right|_{min} = 0.67^{1.3}$$

For a simple system such as the one just discussed where $A = 0$ and $\alpha = \infty$, there is a simple relationship between the damping ratio, ζ and the degree of resonance, M_{max}. This relationship is shown graphically in Figure 7 where a value of $M_{max} = 1.5$ may be seen to correspond to a damping ratio $\zeta = 0.35$. For the more complicated illustrative problem the correspondence between M_{max} and ζ can be seen to remain very similar to that for the simpler system with no delay in the feed-back circuit. This is a peculiarity of this particular problem and has been shown in unpublished work of others not to be a general case.** For more complicated systems the indications are that, when the degree of resonance is limited, the degree of stability can vary over a substantial range. A great deal still can be done to clarify the relationship between criteria for servomechanism design.

In concluding a discussion of the problem used as an illustrative example, it is desirable to point out that the characteristic equation, equation 19, is the same as any that would result from any time delay in the circuit. If, for example, the transfer function of the direct circuit were of the form

$$\frac{\theta_o}{\epsilon} = \frac{K_d}{p(T_d p+1)} \cdot \frac{1}{(T_f p+1)} \qquad (21)$$

where the components formerly in the feed-back circuit are moved to the direct circuit, then

$$\frac{\theta_o}{\theta_i} = \frac{K_d}{p(T_d p+1)(T_f p+1)+K_d} \qquad (22)$$

or

$$\frac{\theta_o(\lambda)}{\theta_i(\lambda)} = \frac{B/A}{\lambda^3+\frac{A+1}{A}\lambda^2+\frac{1}{A}\lambda+B/A} \qquad (23)$$

where λ, A, and B are as defined for equation 14 and equation 15. The denominator of equation 23 is identical to that of equation 18.

The foregoing discussion leads to a general comment on the nature of the transient response resulting from any sudden disturbance, no matter where in the closed loop of a single-loop servomechanism it is inserted; namely, that the system always will recover with the same modes of oscillation and degree of stability and/or with the same exponential decay times. The predominance of one part of the response over another, however, will change, depending on where in the closed cycle the transient disturbance is introduced. This conclusion applies in a limited degree when there are multiloop systems involved.

In a similar way, the system response at the output resulting from a sinusoidal disturbance depends on where the disturb-

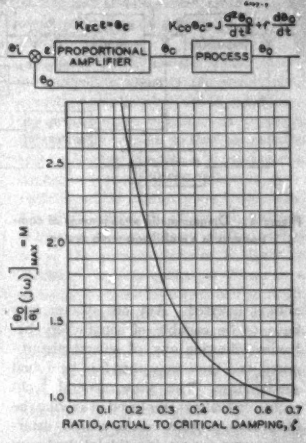


Figure 7. Correlation of degree of resonance M, with the ratio of actual to critical damping, ζ, for a proportional servomechanism

$$M = \frac{1}{2\zeta(1-\zeta^2)^{1/2}} \quad \zeta < 0.707$$

$$\omega_n = \sqrt{K/J}$$

$$K = K_{ec}K_{co}$$

$$\beta = \frac{\omega}{\omega_n}$$

$$\zeta = \frac{f}{2\sqrt{KJ}}$$

Peak of frequency response occurs when

$$\beta = \sqrt{1-2\zeta^2}$$

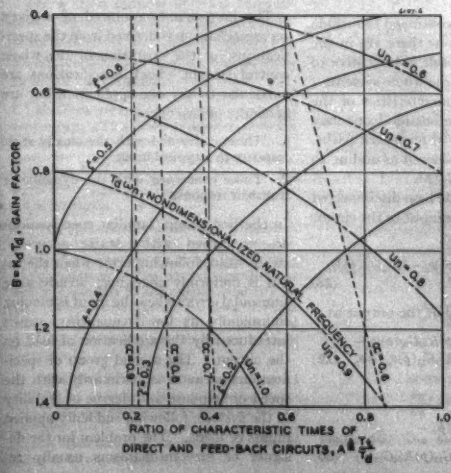


Figure 6. Presentation of the salient features of the transient response of a proportional servomechanism with a time delay in the feed-back circuit as a function of nondimensionalized system parameters

System characteristic equation

$$\lambda^3+\frac{A+1}{A}\lambda^2+\frac{1}{A}\lambda+\frac{B}{A} = (\lambda+\alpha)\times(\lambda^2+2\zeta\omega_n\lambda+\omega_n^2)$$

*The number varies considerably depending on the designer and the application.

**The manner of presentation of the roots of the characteristic equation as functions of system parameters and the comparison of these with similar data from frequency response studies is identical to that used by D. F. Tuttle of Massachusetts Institute of Technology. He compared the criteria for an integral control system.

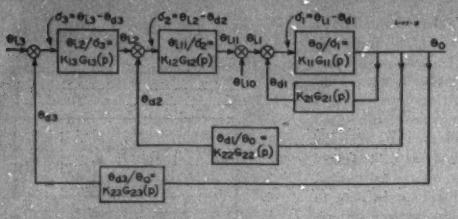


Figure 8. Diagrammatic arrangement of components in a multiloop servo system

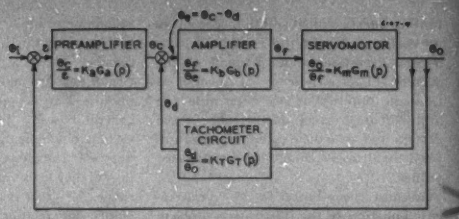


Figure 9. Diagrammatic arrangement of components for use of tachometric feedback in a positional servomechanism

ance is inserted. Any one system may have to be capable of satisfactory behavior following any of several disturbances, and there may therefore be a dual specification. The same general techniques of analysis employed in solving the illustrative problem can be used to determine response to a sinusoidal disturbance somewhere in the closed-cycle and hence be indicative of the transient response to a sudden disturbance at the same place. With reference to Figure 1, if the disturbance is $\theta_i(p)$ between the preamplifier and the servomotor then

$$\frac{\theta_1}{\theta_e} = \frac{1}{K_b G_b(p) K_c G_c(p)} + K_1 G_1(p) K_2 G_2(p) \quad (24)$$

General Treatment of Multiloop Systems

The technique described for the study of a servomechanism whose output quantity is not measured instantaneously is a powerful tool in dealing with much more complicated systems. It is particularly useful for studying systems where there are feed-back paths within feed-back paths, or in another way of speaking, where there are several loops.

A block diagram is drawn as Figure 8 to illustrate a multiloop system in general terms. The number of loops have been limited because the treatment of a larger number of closed loops is a logical extension of the treatment of a limited number.

The reasons for a large number of closed loops in a servomechanism system may be several. There are, however, three most likely reasons for such complicated structures:

1. A servomechanism may be required to serve in more than one capacity wherein it may be used by itself or it may be used, after a switching operation, as a part of an inclusive control system.

2. It may be possible to improve servomechanism performance by the use of compensating networks whereby additional control signals are introduced, in addition to the master input, which is a function of the output quantity or its derivatives or integrals.

3. It may be necessary to measure the output quantity with a device which cannot be considered perfect as compared with the rest of the system.

The following analytical representation of the system of Figure 8 is general, in that it does not define the purpose of the several components.

(*a*). For the inside loop with others disconnected where θ_{i1} is the independent variable

$$\frac{\theta_{i1}}{\theta_o} = \frac{1}{K_{11} G_{11}(p)} + K_{21} G_{21}(p) \quad (25)$$

(*b*). For the second loop with the outside loop disconnected, where θ_{i10} is zero and θ_{i2} is the independent variable

$$\frac{\theta_{i2}}{\theta_o} = \frac{1}{K_{12} G_{12}(p)} \left[\frac{1}{K_{11} G_{11}(p)} + K_{21} G_{21}(p) \right] + K_{22} G_{22}(p) \quad (26)$$

(*c*). For the third loop where $\theta_{i10} = 0$ and θ_{i3} is the independent variable

$$\frac{\theta_{i3}}{\theta_o} = \frac{1}{K_{13} G_{13}(p)} \left[\frac{1}{K_{12} G_{12}(p)} \left(\frac{1}{K_{11} G_{11}(p)} + K_{21} G_{21}(p) \right) + K_{22} G_{22}(p) \right] + K_{23} G_{23}(p) \quad (27)$$

which process can be continued to include as many closed loops as there are in the system. The final result is indicative of the characteristics of the whole system.

To consider the characteristics of the inside closed loop, the outside loops may be treated as additional feed-back paths. If an input θ_{i10} is considered as adding to the output from $K_{11} G_{11}(p)$.

(*a*). For the outside loop disconnected and θ_{i2} held at zero the input to the circuit $K_{11} G_{11}(p)$ is

$$\theta_{i10} + [K_{12} G_{12}(p) K_{22} G_{22}(p)] \theta_o - [K_{21} G_{21}(p)] \theta_o \quad (28)$$

and this is reproduced at the output as

$$K_{11} G_{11}(p) [\theta_{i10} + K_{13} G_{13}(p) K_{23} G_{23}(p) \theta_o - K_{21} G_{21}(p) \theta_o] = \theta_o \quad (29)$$

or

$$\frac{\theta_{i10}}{\theta_o} = \frac{1}{K_{11} G_{11}(p)} + K_{21} G_{21}(p) - K_{13} G_{13}(p) K_{23} G_{23}(p) \quad (30)$$

which is a result which can be obtained by the addition of a new vector locus to the original one, equation 25, for the inside loop with the others disconnected.

(*b*). If the third loop as well as the second loop is connected and θ_{i3} held at zero, then the quantity σ_3 is the difference between θ_{i3} and θ_{d3}, and this is a simple addition to equation 30

$$\frac{\theta_{i10}}{\theta_o} = \frac{1}{K_{11} G_{11}(p)} + K_{21} G_{21}(p) + K_{13} G_{13}(p) \times [K_{23} G_{23}(p) K_{13} G_{13}(p) - K_{23} G_{23}(p)] \quad (31)$$

The foregoing process may be continued to include as many loops as are necessary. Even though the systems are very complicated, there is a reasonable way to consider the effect of change in any of the circuits by graphical construction of the loci of the reciprocal system function, where the operator is $(j\omega)$, and by observation of its salient characteristics.

Comments on Compensating Networks

The performance required of a given servomechanism is derived from the specifications for the operation of the whole control system. Such specifications are particular to any one application but are generally of two types

1. Those concerned with the steady state response to a typical input.

2. Those concerned with the dynamic or transient response.

In the first group, familiar specifications are concerned with: static accuracy; steady-state following error when the input is uniformly changing; steady-state sinusoidal errors when the input is moving sinusoidally at low frequencies; errors introduced by the application of load on the output. The second group of specifications is concerned primarily with the speed of response and degree of stability of the system, following suddenly applied inputs or loads. The problem for the designer of servomechanisms usually re-

solves itself into determining means for obtaining the desired steady-state response without harming the dynamic response characteristics.

In accomplishing his purpose in designing servomechanisms, the engineer usually resorts to the use of certain general techniques which are economic of equipment and which often make the control system feasible. These techniques center around

1. The close specification of the characteristics of the process, so that it is more controllable.

2. The use of special control circuits.

One widely used technique is to make the control amplifier sensitive to derivatives and integrals of the servo error as well as the error itself. The controller then is described as one which anticipates and remembers. The general purpose of the use of derivatives of error is to improve the degree of stability of the system, thereby making possible larger sensitivity. The general purpose in the use of integrals of the error is to increase the system sensitivity statically or at low frequencies without materially harming the performance of the system at frequencies where it is likely to oscillate. The techniques for the design of these compensating devices are not the main concern of this paper. They have been discussed widely (see reference list) and can be treated as cascaded elements in the system. In Figure 1, a change in the controller, represented by the operational transfer function $K_1G_1(p)$, can be treated readily since it is multiplied by the transfer functions of the remaining cascaded elements. This has been indicated previously in equation 1.

There are a number of other compensating networks which cannot be accurately described as cascade elements in the control system. Several examples of these are enumerated:

1. Feedback around a component or group of components. This often is done to improve the dynamic response of elements or to remove the dependence on open-loop instrumentation in the action of an element. Integral controllers sometimes are made by the use of feedback.

2. Output feedback. It is often possible to obtain a stabilizing device by returning signals to the controller which are functions of the derivatives of the output quantity, as well as functions of the output quantity itself. When these signals are used without subtracting them from similar functions of the input, then they are no longer cascade elements.[1,8]

3. Input feed-forward. This is a term used to describe systems which measure a function of the derivatives of the input as well as the input itself, thus supplying the control system with advance knowledge of what is going to be required of it.[9]

4. Tuned loads. These are used to impose a restraint on the output member which is frequency sensitive. They are devices that limit the ability of the output member to oscillate at the resonant frequency of the system.

All of the afore-mentioned techniques are fairly complicated in their application. It is not practicable to treat them all, and the opportunity to obtain general solutions is limited. They can, however, be studied quite satisfactorily by the use of appropriate system functions. The remainder of this paper will deal with an illustrative example wherein output feedback is used to improve the performance of the system.

Tachometric Feedback in Positional Servomechanisms

If the speed of the output of a position control is measured, and a function of this signal is fed back degeneratively into the amplifier stages, where it is added to the positional error signal, the performance of the servomechanism may be improved. This may be visualized physically by comparing this technique with that of employing the derivative of the servo error. When the servo input is stationary, the two are identical in function if the tachometric signal is not modified by some additional network. It would be concluded, therefore, that tachometric feedback has a stabilizing effect, since the good use of error derivative techniques is well known.[1,2]

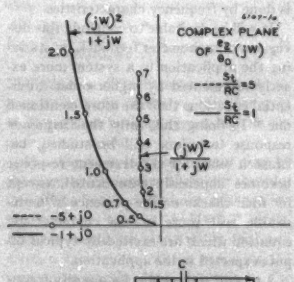


Figure 10. D-c tachometer with high-pass filter

Actually the tachometer signal usually is modified to improve the steady-state error that results when the input is moving at a constant velocity. A high-pass filter usually is used, so that no signal is sent back when the output is moving at a constant velocity or is following sinusoidal inputs of relatively low frequencies. The filter, however, allows the tachometer signal to pass freely at frequencies where the servomechanism is likely to oscillate. A simple filter is shown in a tachometer circuit as a part of Figure 10. By this technique the stabilizing effect of the tachometer is made available at frequencies where the servomechanism is likely to oscillate and does not require an even greater error signal to make the output move at a given speed.

The tachometer signal need not be added to the control system at the same place where the positional error signal is introduced. A general arrangement of components is illustrated in block diagram form in Figure 9. The preamplifier may use an integrating circuit or some other compensating circuit if the specifications for the servomechanism cannot be met without their use. For the first example to be discussed here the amplifier will be assumed to be proportional and characterized by a gain factor, K_a. Also in the first example it will be assumed that the servomotor is one in which the output damping is negligible and that the inertia of the motor and output member is the only energy storage element on the output shaft. Under these conditions the transfer function $K_mG_m(p) = K_m/J_mp^2$. Without the use of some sort of compensating device this system would be unstable. To stabilize the system let the tachometer circuit of Figure 10 be used. The amplifier $K_bG_b(p)$ will be assumed to be proportional and to have no time lags. Equations for the system may be written on the basis of the foregoing simplifications:

$$\theta_a = \theta_c - \theta_d = K_a\epsilon - \frac{S_tRCp\theta_0}{RCp+1} \tag{32}$$

$$\theta_0 = \frac{J_mp^2}{K_bK_m}\,\theta_a \tag{33}$$

from which

$$\frac{\epsilon}{\theta_0} = \frac{1}{K_aK_m}\left[\frac{J_mp^2}{K_bK_m} + \frac{S_tRCp^2}{RCp+1}\right] \tag{34}$$

and since by definition, $\epsilon = \theta_i - \theta_0$

$$\frac{\theta_i}{\theta_0} = 1 + \frac{1}{K_aK_m}\left[\frac{J_mp^2}{K_bK_m} + \frac{S_tRCp^2}{RCp+1}\right] \tag{35}$$

which may be written in the form

$$\frac{\theta_i}{\theta_o}=1+\frac{S_i}{K_aRC}\left[\frac{J_m}{RCK_bK_mS_i}\lambda^2+\frac{\lambda^2}{\lambda+1}\right] \quad (36)$$

where $\lambda=RC\rho$. If the right hand side of equation 35 is expressed in terms of a common denominator, the numerator of the resulting fraction is the characteristic equation when equated to zero.

$$J_mRC\rho^3+(K_bK_mS_iRC+J_m)\rho^2+K_aK_bK_mRC\rho+K_aK_bK_m=0 \quad (37)$$

The characteristic equation may be written in terms of λ instead of ρ and two nondimensional parameters defined

$$F=\frac{J_m}{RCK_bK_mS_i} \quad (38)$$

$$D=\frac{S_i}{K_aRC} \quad (39)$$

$$\lambda^3+\left(1+\frac{1}{F}\right)\lambda^2+\frac{1}{FD}\lambda+\frac{1}{FD}=0 \quad (40)$$

Equation 40 is in a form where it may be broken down readily into a study of the real and quadratic factor. These factors could be expressed graphically as functions of F and D in a manner similar to Figure 6.

An important deduction can be made with reference to equations 38 and 39. It can be seen that F and D may be controlled separately in magnitude by adjustment of the time constants and component sensitivities in the system. This means that mathematically any desired result may be obtained for the response of the system.

There are two practical limitations on the procedure of unlimited adjustment. The first, and most important, is that no physical system can be represented by such simple differential equations as a first order approximation when the natural and resonant frequencies for the system become very high. The second limitation is that the specifications for the performance of the servomechanism do not, as a rule, justify the expense in equipment in obtaining better performance than is required.

By using the same substitutions given in equations 37, 38, and 39 the frequency response loci may be studied in accordance with the functional relationship indicated by equation 35. Setting $\lambda=jW$

$$\frac{\theta_i}{\theta_o}(jW)=1+D\left[F(jW)^2+\frac{(jW)^2}{1+jW}\right] \quad (41)$$

Figure 11 shows an example of the construction of typical loci for one particular value of D and two values of F. In drawing these loci, it would have been as easy to construct them by adding to the locus of

$$\frac{(jW)^2}{1+jW}$$

shown in Figure 10, the locus of $F(jW)^2$ and work with the resultant locus as a reciprocal system function

$$\frac{\epsilon}{\theta_o}(jW)$$

The polar expansion of this locus is controlled by the gain factor D.

The same conclusion about the adjustment of the system may be reached from a study of the frequency loci as was reached from a study of the characteristic equation; namely, that any response desired could be obtained by appropriate selection of parameter values.

There is, however, one important failing of this technique in that there is no simple way known to the author that has yet been evolved to see the presence of predominating real roots in the transient response by simple examination of the locus. It has been suggested that the rate of change of phase near zero frequency might hold a clue, but this has not been investigated thoroughly. Even in a complicated system, however, it is not a long problem to evaluate a real root and its coefficient for particular values and for a specified disturbance. Hence, there is the desirability of always keeping in close touch with the transient specifications of a system when the major part of the study is done by frequency characteristics.

It will be desirable to conclude this discussion of tachometer feedback by studying the application to a system more exactly represented by higher order differential equations than the afore-mentioned one. In doing this, only the frequency response technique will be studied, because a study of the transient response becomes hopelessly complicated, except for final checks on the presence of undesirable real roots in the characteristic equation which are excited by typical inputs expected in the application.

A typical servomotor for a position controller will be an integrating device with an elastance storage element as well as an inertia storage element. The transfer function, K_mG_m, for such a servomotor would be of the form

$$K_mG_m(\rho)=\frac{S_m}{\rho(J_m\rho^2+f_m\rho+k_m)} \quad (42)$$

where K_m is S_m/k_m and is expressible as per unit speed output per unit input. If the numerator and denominator of equation 44 are divided by k_m, and the open-loop undamped natural frequency of this component be written as $\omega_n=k_m/J_m$, and the ratio of actual to critical damping of the open-loop characteristic be written as

$$\zeta=\frac{f_m}{2\sqrt{J_mk_m}}$$

then equation 44 may be rewritten

$$K_mG_m(\rho)=\frac{\frac{K_m}{\omega_n}}{\frac{1}{\omega_n}\rho\left(\frac{1}{\omega_n^2}\rho^2+\frac{2\zeta}{\omega_n}\rho+1\right)} \quad (43)$$

and transformed, when

$\lambda=\frac{1}{\omega_n}\rho$ into

$$K_mG_m(\lambda)=\frac{S_m/k_m\omega_n}{\lambda(\lambda^2+2\zeta\lambda+1)} \quad (44)$$

The amplifier used with such a power motor probably has an open-loop speed of response of the same order of magnitude as the servomotor itself. If the transfer function of the amplifier be assumed to be of the form

$$K_bG_b(\rho)=\frac{K_b}{\tau\rho+1} \quad (45)$$

where the characteristic time, τ, is arbitrarily set equal to $1/\omega_n$, which is commensurate with the foregoing statement regarding its speed of response, equation 45 then may be rewritten in terms of

$$K_bG_b(\lambda)=\frac{K_b}{\lambda+1} \quad (46)$$

The cascade of the amplier and servomotor then may be written as

$$K_mG_m(\rho)K_bG_b(\rho)=\frac{\frac{K_bK_m}{\omega_n}}{(\lambda+1)(\lambda^2+2\zeta\lambda+1)\lambda} \quad (47)$$

The preamplifier will be assumed to be characterized by a gain K_a and negligible characteristic time.

If the components are assembled in a servomechanism without tachometer feedback and the gain of the system

$$\frac{K_aK_bK_m}{\omega_n}$$

be adjusted to give the highest resonant frequency possible with a peak degree of resonance

$$\left|\frac{\theta_i}{\theta_o}\right|_{min}$$

of 0.7, then the resulting frequency locus will be as shown in Figure 12 where $\zeta=0.3$ and $\lambda=j\mu$. The gain adjustment was such as to make

$$\frac{K_aK_bK_m}{\omega_n}=\frac{1}{2.8}$$

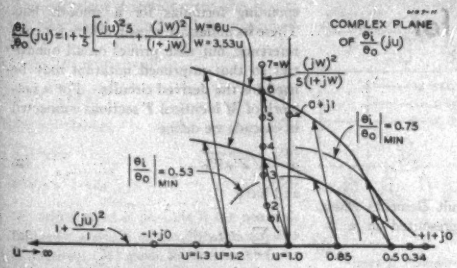


Figure 11. Loci illustrating a study of the application of tachometer feedback to a proportional servomechanism whose output member is characterized by load inertia and no damping

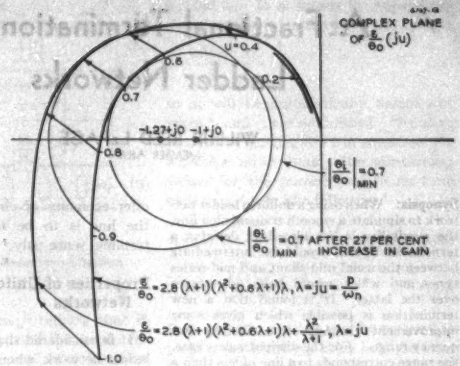


Figure 12. Loci illustrating a study of the application of tachometer feedback to a positional servomechanism with four energy storage elements

If, now, tachometer feedback is to be added to the system, the analytical combination of the system is indicated in equation 48.

$$\frac{\epsilon}{\theta_o} = \frac{1}{K_a K_m G_m(p) K_b G_b(p)} + K_t G_t(p) \qquad (48)$$

which is derived for the system block diagram of Figure 9.

The type of tachometer feedback used will be that illustrated in Figure 10, so that

$$K_t G_t(p) = \frac{\frac{S_t}{RC} R^2 C^2 p^2}{RCp+1} \qquad (49)$$

A question immediately arises about the magnitude of the tachometer signal that can be made available, or in other words what is a reasonable value of K_t with respect to the sensitivity of the amplifier and servomotor in cascade. If K_t were exactly equal to $1/K_m K_b$ then, in the absence of the tachometer RC network, the amplifier K_a would have to supply just twice as much signal to make the output run at a given speed as it would in the absence of the tachometer. Calculation would show that a locus resulting from substitution in equation 50 would be altered very little by the addition of tachometer feedback with so low a tachometer sensitivity, unless the characteristic time of the RC network is made very large. Unfortunately, if the characteristic time of the RC network is made much larger than those in the remainder of the system, the speed of response of the servomechanism will be reduced by the introduction of a predominant exponential decay in the transient response. This conclusion is largely an experience deduction based on heuristic reasoning about the flow of correcting signals through the circuits. However, it has been substantiated by actual calculation in a number of instances.

In Figure 12 the original locus is shown modified by a tachometer feed-back circuit with the particular adjustment

$$RC = \frac{1}{\omega_n} \qquad (50)$$

and

$$K_t = \frac{S_t}{RC} = \frac{\omega_n}{K_a K_m K_b} = 2.8 \qquad (51)$$

The addition of tachometer feedback allows an increase in the preamplifier gain of 27 per cent without increasing the degree of resonance.

The allowable increase in gain may be obtained by evaluating the polar contraction of the final locus before again becoming tangent to the $1/M = 0.7$ circle. Another technique is to find by trial and error a new circle, whose radius is 0.7 times the length along the axis to the center, that will be tangent to the new locus. The amount by which the gain may be increased is read immediately from the scale on the negative real axis.

In summary it cannot be emphasized too strongly that the major value of such analytical techniques as are described here is to give a quantitatively approximate idea of the correct approach to a problem. However, when the analysis includes experimental data on the performance of the major components, then the design of the remaining circuits can be done very exactly, although always subject to check on the applicability of the criteria used for design.

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A Fractional Termination for Ladder Networks

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Synopsis: When using a uniform ladder network to simulate a smooth transmission line, the possibility is considered of deriving a termination which would be intermediate between the usual mid-shunt and mid-series types and which would have advantages over the latter. It is found that a new termination is possible which gives some improvement throughout a limited frequency range. For the dissipationless case, the range corresponds to a line of less than a quarter wave length. The improvements attainable are of the order of a few per cent and become less significant the greater the number of network sections. Thus, although the formula for the new termination and the estimates of the results which it will accomplish are given for any number of sections, the new termination is of most practical value for circuits of few sections. In arriving at this termination, consideration is given to the variation of each of the elements of the pair on each end; but of these two, the end element is the only one whose variation yields an improvement. For the frequency range for which the modified circuit is an improvement, the distinction between the two original types of termination largely is lost, the modified midshunt and modified mid-series terminations being almost identical. Beyond this range there is a difference between them, and the corresponding original and new networks are nearly equivalent. A possible application of the results is suggested in which the simulation of a smooth line is not involved.

IT is well known that by taking a sufficient number of sections, a mid-shunt or mid-series terminated uniform ladder network may be made to approximate a smooth line as closely as desired over a low-pass band of frequencies the width of which increases as the number of network sections is increased. It is also true, considering the network in the 4-terminal sense, that under some conditions a mid-shunt termination gives the best results while with other terminal conditions the mid-series arrangement is superior. The question to be treated is whether an intermediate termination can be found which will give a uniformly good approximation for all conditions and, if possible, a superior performance. This is to be investigated with the understanding that the network must retain its 4-terminal identity, which implies symmetry about the line indicated in Figure 1. This rules out known nonuniform networks that offer economy of circuit elements when the line is to be represented in a 2-terminal sense only.[1]

Properties of Uniform Ladder Networks

It is considered that an analysis of the ladder network, when terminal quantities are involved, is most reasonably carried out in terms of the 4-terminal network parameters A, B, and C, which are defined by the equations

$$E_S = AE_R + Z_T BI_R \tag{1a}$$

$$I_S = Y_T CE_R + AI_R \tag{1b}$$

in the symmetrical case. The voltages and currents involved are indicated in

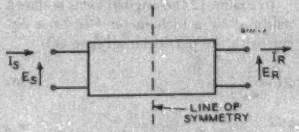

Figure 1. Notation for a 4-terminal network

Figure 1, and Z_T and Y_T are respectively the total series impedance and shunt admittance of the line. This notation is slightly different from the usual practice in that B and C are written respectively with the factors Z_T and Y_T removed. This change simplifies many of the subsequent equations. One may obtain the quantities that are necessary for expressing the circuit in other forms from equations involving A, B, and C, which may be found in standard texts on circuit analysis.[2]

Expressions for A, B, and C in power series of the variable $Z_T Y_T$ have been given in a previous paper[3] for a uniform ladder network with either type of termination. The series form is used because it affords simple comparisons with corresponding formulas for a smooth line. These formulas are repeated here for easy reference, but with primes on all quantities so that unprimed notation may be used for the derived circuits. For a network of M identical T sections connected in cascade we define

$$\alpha' = \sqrt{Z'_T Y'_T} \tag{2}$$

and have

$$A' = \sum_{\lambda=0}^{M} a'_\lambda (\alpha')^{2\lambda} \tag{3a}$$

$$B' = \sum_{\lambda=0}^{M} b'_\lambda (\alpha')^{2\lambda} \tag{3b}$$

$$C' = \sum_{\lambda=0}^{M-1} c'_\lambda (\alpha')^{2\lambda} \tag{3c}$$

in which

$$a'_\lambda = \frac{1}{(2\lambda)!} \prod_{n=0}^{\lambda-1} \left(1 - \frac{n^2}{M^2}\right) \tag{4a}$$

$$b'_\lambda = \frac{1}{(2\lambda+1)!} \left(1 + \frac{\lambda}{2M^2}\right) \prod_{n=0}^{\lambda-1} \left(1 - \frac{n^2}{M^2}\right) \tag{4b}$$

$$c'_\lambda = \frac{1}{(2\lambda+1)!} \prod_{n=0}^{\lambda} \left(1 - \frac{n^2}{M^2}\right) \tag{4c}$$

The corresponding results for M identical π sections in cascade are obtained by interchanging B' and C',[3] and the corresponding coefficients for a smooth line are obtained from equations 3 and 4 by allowing M to become infinite. The parameters and coefficients for the smooth line subsequently will be referred to as ideal values and will be written with a bar above the appropriate symbol.

Modified Terminations

The simple relationship between the B and C parameters of the T and π section constructions maintains even when all network sections are not identical, so long as the modifications of corresponding elements of the two networks are related dually.[3] That is, so long as a given change in a series element of one network is represented by an equivalent change in the corresponding shunt element of the other network, we need treat only one network. This enables us to proceed by analyzing only the T-section case.

The algebra is simplified if we assume an ordinary mid-series terminated uniform network on each end of which is connected a new series element. The new total series impedance will be designated by Z_T, and the element added to each end will be of magnitude ρZ_T. These definitions are illustrated in Figure 2A, along with Figure 2B, which shows

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the equivalent π-section case, the results for which will be included, as explained above.

For the new circuit

$$\alpha = \sqrt{Z_T Y_T} \tag{5a}$$

$$Z'_T = (1-2\rho)Z_T \tag{5b}$$

$$Y'_T = Y_T \tag{5c}$$

$$\alpha' = \alpha\sqrt{1-2\rho} \tag{5d}$$

No adjustment is possible if the network has only a single section, so the number of sections (M) must be greater than or equal to 2. The formulas for A, B, and C, the new network parameters, are easily obtained by considering the network to be formed by the cascade connection of three elemental networks as indicated in Figure 2. This connection lends itself to the use of matrix algebra in the following way:[4]

$$\begin{pmatrix} A & BZ_T \\ CY_T & A \end{pmatrix} = \begin{pmatrix} 1 & \rho Z_T \\ 0 & 1 \end{pmatrix} \times \begin{pmatrix} A' & B'Z'_T \\ C'Y'_T & A' \end{pmatrix} \begin{pmatrix} 1 & \rho Z_T \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} A'+\rho C'\alpha^2 & [2A'\rho + B'(1-2\rho) + \rho^2 C'\alpha^2]Z_T \\ C'Y_T & A'+\rho C'\alpha^2 \end{pmatrix} \tag{6}$$

The formulas for A, B, and C may be picked from the matrix on the right of the above equation. Equations 3a–3c are used for A', B', and C' with the observation that the $(\alpha')^{2\lambda}$ factors may be replaced by $\alpha^{2\lambda}(1-2\rho)^{\lambda}$. Also, noting that whenever the term α^2 appears in the final matrix of equation 6, it always carries C' as a coefficient, and that the maximum exponent in the series for C' is two less than in the series for A' or B', it follows that the maximum exponents of α in the series for A, B, and C will be the same as in equations 3a–3c. Hence

$$A = \sum_{\lambda=0}^{M} a_\lambda \alpha^{2\lambda} \tag{7a}$$

$$B = \sum_{\lambda=0}^{M} b_\lambda \alpha^{2\lambda} \tag{7b}$$

$$C = \sum_{\lambda=0}^{M-1} c_\lambda \alpha^{2\lambda} \tag{7c}$$

Formulas for a_λ, b_λ, and c_λ are obtained from the individual elements of the last matrix of equation 6, in conjunction with equations 3a–3c. The results are

$$a_\lambda = a'_\lambda(1-2\rho)^\lambda + \rho c'_{\lambda-1}(1-2\rho)^{\lambda-1} \tag{8a}$$

$$b_\lambda = 2\rho a'_\lambda(1-2\rho)^\lambda + b'_\lambda(1-2\rho)^{\lambda+1} + \rho^2 c'_{\lambda-1}(1-2\rho)^{\lambda-1} \tag{8b}$$

$$c_\lambda = c'_\lambda(1-2\rho)^\lambda \tag{8c}$$

In formula 8a, a negative subscript is understood to indicate a value of zero for that coefficient. At this point it is well

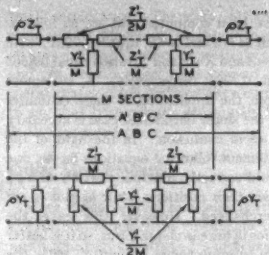

Figure 2. Single-element modification

to make the cautionary remark that if these are to be interpreted for the shunt-terminated case, it is only the formulas for b_λ and c_λ that should be interchanged. Reflection will show that b'_λ and c'_λ must not be interchanged if they are still given by equations 4a–4c. Of course, if an exchange is made there also, the change should be made in equations 8a–8c as well. In other words, if b'_λ and c'_λ are not interchanged, they retain their significance of respective coefficients of B' and C' for a uniform mid-series terminated network, while if they are interchanged, their new significance relates to a mid-shunt terminated uniform network.

The condition for the new termination has been stated as the removal of the distinction between series and shunt element termination with, if possible, an improvement in the approximation for a smooth line. The non-equivalence of the two ordinary terminations arises from the non-equality of b'_λ and c'_λ in equations 4a–4c. One therefore proceeds by first making $b_\lambda = c_\lambda$ for as many values of λ as possible, starting from $\lambda = 0$, and later checking whether they are less in error than their corresponding primed coefficients. From equations 4a–4c it is seen that a'_0, b'_0, and c'_0 each has its correct value, and from equations 8a–8c it follows that

$$a_0 = b_0 = c_0 = 1 \tag{9}$$

It also is seen from equation 8a, and the fact that $a'_1 = 1/2$ and $c'_0 = 1$, that

$$a_1 = a'_1(1-2\rho) + \rho c'_0 = 1/2 \tag{10}$$

Thus, to have the first terms correct in the power series expansions of B and C and to have the first two terms correct in the expansion of A, it is only necessary to have the total series impedance and shunt admittance equivalent to those of the simulated line so α will have the correct value.

Attention logically is turned next to a_2, b_1, and c_1. It is shown in Appendix I that these are interrelated by the formula

$$a_2 = \frac{b_1 + c_1}{2} - \frac{1}{8} \tag{11}$$

so a_2 will be automatically determined when b_1 and c_1 are established. We shall proceed by putting $\lambda = 1$ in equations 8b, 8c, and so on to obtain, after substituting values for the primed coefficients from equations 4a–4c, the following:

$$b_1 = \rho(1-2\rho) + (1-2\rho)^2\left(\frac{1}{6}\right)\left(1+\frac{1}{2M^2}\right) \tag{12a}$$

$$c_1 = (1-2\rho)\left(\frac{1}{6}\right)\left(1-\frac{1}{M^2}\right) \tag{12b}$$

Formulas 12a and 12b may be equated to yield a quadratic equation in ρ the solution of which readily is found to be

$$\rho = 1 - \frac{1}{2}\sqrt{\frac{4M^2-1}{M^2-1}} \tag{13}$$

The negative sign is chosen for the radical from knowledge that $\rho = 0$ must correspond to infinite M. It is interesting to note that ρ is negative, implying a reduction of the end element. This is reasonable because it physically means a compromise between the two ordinary terminations. The substitution of this value of ρ in equation 12b gives

$$b_1 = c_1 = \frac{1}{6}\sqrt{1-\frac{1}{M^2}} \times \left(2\sqrt{1-\frac{1}{4M^2}} - \sqrt{1-\frac{1}{M^2}}\right) \tag{14}$$

It remains to be seen whether this value is less in error than b'_1 and c'_1. It should be noted parenthetically that when comparisons are to be made between the new and the old coefficients, the latter must represent a network having the same over-all impedance and admittance as the new circuit. This only affects A', B', and C', through Z'_T, Y'_T, and α', and not a'_λ, b'_λ, and c'_λ. It is only the interpretation which is affected by varying Z'_T, and Y'_T. This is equivalent to saying that the primes may be removed from Z'_T, Y'_T, and α', but that they must be retained on the parameters and coefficients. It will be assumed that this is done for all the subsequent comparisons.

The error of $b_1 = c_1$, as given by equation 14, may be estimated by the process shown in Appendix II. It is found that

$$\frac{1}{24M^2} < \frac{1}{6} - c_1 = \frac{1}{6} - b_1 < \frac{3}{49M^2} \tag{15}$$

while the errors of b'_1 and c'_1 are, from equations 4a–4c,

$$b'_1 - \frac{1}{6} = \frac{1}{12M^2} \tag{16a}$$

$$\frac{1}{6}-c'_1=\frac{1}{6M^2} \tag{16b}$$

It thus is assured that the errors in b_1 and c_1 are less than those in b'_1 and c'_1.

An estimate of the error in the corresponding a_2 may be obtained from equation 11 and inequality 15. One directly obtains

$$\frac{1}{24M^2}<\frac{1}{24}-a_2<\frac{3}{49M^2} \tag{17}$$

It is also important to know how it compares with its value when $\rho=0$. An estimate of the ratio a_2/a'_2 can be found by a procedure shown in Appendix III which gives

$$\frac{(M^2-1/4)(M^2-7/4)}{(M^2-1)^2}<\frac{a_2}{a'_2}<\frac{(M^2-2/5)(M^2-8/5)}{(M^2-1)^2}<1 \tag{18}$$

This remains near, but less than, unity. The estimate is less accurate when M is small, so actual values of the ratio are tabulated in Table I along with the ratios of a'_2, a_2, b'_1, $b_1=c_1$, and c'_1 to their ideal values. One must observe that the error in a_2 is greater than the error in a'_2. This follows from equation 4a, which shows that a'_2 is less than $\bar{a}_2$, and from relation 18, which shows a_2 to be less than a'_2.

When $|\alpha|$ is sufficiently small, only the first two terms in each of the series for A', B', and C' will be important because it is known that the coefficients decrease with increasing λ. Therefore if the coefficients for the new circuit, when λ is greater than or equal to 2, are not brought into prominence by the modification, the new circuit will have less error and will be more symmetrical in B and C, for this range of $|\alpha|$. Estimates of a_λ, b_λ, and c_λ are therefore in order for $\lambda\geqq 2$. The methods used in obtaining these estimates are illustrated in Appendix III, with the results given in the following inequalities:

$$\left(\frac{M^2-2/5}{M^2-1}\right)^{\lambda-1}\left(\frac{M+1/4}{M+1}\right)<\frac{a_\lambda}{a'_\lambda}<\left(\frac{M^2-1/4}{M^2-1}\right)^{\lambda-1}\left(\frac{M^2-11/5}{M^2-1}\right)$$
$$\lambda\geqq 3,\ M\geqq 3 \tag{19a}$$

$$\left(\frac{M^2-2/5}{M^2-1}\right)^{\lambda-1}\left(\frac{M-1}{M+1}\right)<\frac{b_\lambda}{b'_\lambda}<\left(\frac{M^2-1/4}{M^2-1}\right)^{\lambda-1}\quad \lambda\geqq 2,\ M\geqq 4 \tag{19b}$$

$$\left(\frac{M^2-2/5}{M^2-1}\right)^{\lambda}<\frac{c_\lambda}{c'_\lambda}<\left(\frac{M^2-1/4}{M^2-1}\right)^{\lambda}$$
$$\lambda\geqq 2,\ M\geqq 2 \tag{19c}$$

The second of these is valid only for $M\geqq 4$ for a reason which is pointed out with its derivation. The actual values of b_λ/b'_λ for the range not covered by relation 19b have been computed and are as follows: with $M=2$ and $\lambda=2$, ratio $=0.7221$; with $M=3$ and $\lambda=2$ and 3, ratios equal 0.8505 and 0.7965, respectively. A statement about the application of these estimates for the shunt terminated case is necessary to avoid confusion. In the light of the statement following equations 8a–8c, one would correctly conclude that b'_λ and c'_λ retain their positions, while b_λ and c_λ are interchanged. However, this leaves the ratios in unreasonable forms, so it is better here to interchange b'_λ and c'_λ with the understanding that they are given by formulas 4a–4c in an interchanged condition. This is in agreement with the alternative proposition contained in the statement referred to. Relations 19a–19c make it clear that none of the coefficients is greatly changed by the modification.

Before continuing with the investigation, the meaning of these results will be discussed rather fully because they have a bearing on the development to follow. It has been pointed out that the B and C coefficients for the new circuit are more nearly equal, and are nearer the ideal value, only so long as $|\alpha|$ is sufficiently small to make the first two terms predominant in the series for A, B, and C. It would be convenient to be able to specify this range definitely, but it depends on the circuit termination and on the angle of the complex number α. Something can be said about the range, however. In the following discussion the range of $|\alpha|$ over which the new circuit is an improvement will be referred to as the useful range. From equation 11, if we take Δb_1 and Δc_1 as the respective errors of b_1 and c_1, it follows that the error (Δa_2) in a_2 is

$$\Delta a_2=\frac{\Delta b_1+\Delta c_1}{2} \tag{20}$$

Considering these terms only, we see that when $|\alpha|=1$ the error in A caused by Δa_2 is as great as the averaged errors of B and C caused by Δb_1 and Δc_1. For larger $|\alpha|$ the error of A will become rapidly worse because a_2 is the coefficient of α^4, while b_1 and c_1 are coefficients of α^2. Thus it would seem that the useful range is about $|\alpha|<1$. However, when considering a_2, it must be remembered that its error is only slightly less in the original circuit. Since we are discussing improvements, although a_2 may cause more error in A than the errors of b_1 and c_1 cause in B and C, the new circuit actually still may be better so long as B and C are more accurate. This argument is reinforced by the realization that in use the B and C parameters have multiplying factors which depend on Z_T and Y_T, and on the terminal conditions. Thus A, B, and C may have different effects on the performance and, so long as B and C are less in error and the error in A is not too much greater, the new circuit may be better. An exceptional case would be one in which the original circuit errors in A and B or C were mutually compensating. In view of these ideas, it would seem logical to define the useful range as that range for which the errors in B and C remain less than in the original circuit, with the understanding that some cases may arise for which the new circuit is not better beyond $|\alpha|=1$. This still does not lead to a unique definition, but it does lead to the expectation of a range somewhat greater than $|\alpha|<1$ because b_2 and c_2 are each much less than a_2 and do not need to be considered until $|\alpha|$ is considerably greater than unity.

Some estimates of the useful range for the dissipationless case may be obtained from Figure 3. A', B', C', A, B, and C are shown as functions of $\alpha=j\omega\sqrt{LC}$ (L and C being the respective total inductance and capacitance of the line) for three values of M. From these graphs a range of $|\alpha|<1.5$ seems to be reasonable for this condition. This range is sensibly independent of M, a consequence of having improved only b_1 and c_1 in all cases. The only advantage of increasing M is to make the errors smaller. This statement refers of course only to the useful range. Increasing M reduces the errors of all circuits for larger $|\alpha|$.

The estimates given in relation 19 are applicable in judging the relative behavior of the circuits beyond the useful range. The percentage variations of the coefficients of order higher than $\lambda=1$ may be of the same order of magnitude as the percentage improvements realized in b_1 and c_1. However, the latter are significant because those coefficients are nearly correct, while for the former the errors are so large as to make the changes of

Table I

M	$a'_2/\bar{a}_2$	a_2/a_2	a_2/a'_2	$b'_1/\bar{b}_1$	$b_1/b'_1=c_1/c'_1$	$c'_1/\bar{c}_1$
2	0.7500	0.7083	0.9443	1.1250	0.9333	0.7500
3	0.8333	0.8313	0.9916	1.0555	0.9703	0.8333
4	0.9375	0.9353	0.9976	1.0313	0.9838	0.9375
5	0.9600	0.9590	0.9990	1.0200	0.9900	0.9600

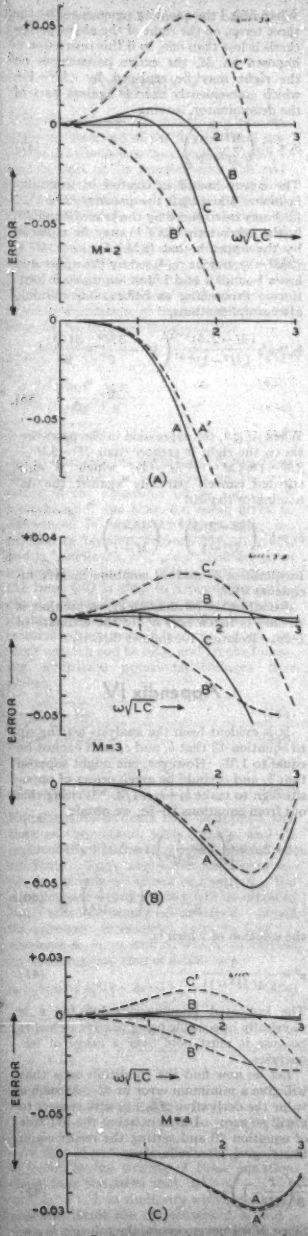

Figure 3. Performance of a dissipationless modified network

small significance. Therefore, although there will be differences, we should expect no appreciable difference between the new and old circuits when $|\alpha|$ is beyond the useful range. It is perhaps more correct to say that both circuits are equally bad in this extended range.

Other Modifications

Since the large error in a_2 may prevent the full realization of the gains made in b_1 and c_1, one may ask whether a more useful circuit might not be obtained if one could reduce the error of a_2 by allowing b_1 and c_1 to have errors of opposite algebraic sign. This question is treated in Appendix IV with results which are negative. It also is shown there that the minimum possible error in a_2 comes when the circuit is unmodified.

The above statements are with respect to variations of only the end elements. The possibility of improving a_2 by modifying the elements second from the end is considered in Appendix V. No improvement is found. The minimum possible error in a_2 still maintains when there is no modification at all. Furthermore, if b_1 and c_1 are again made equal, their minimum error comes when the shunt element has its uniform-network value and the terminal elements are modified in the manner already described (speaking of the series-element terminated case). Corresponding conclusions, of course, would follow if the shunt-element terminated case were treated. No analysis was made to determine the effects of modifying other elements of the network.

Conclusions

Within the limits afforded by the consideration of the end pair of elements, it has been shown that the best modification is that of the end elements alone. The specification for that modification is given below, in terms of the parameter $k=-2\rho$ which is introduced because ρ is negative. We have

$$\frac{Z'_T}{2M}+\rho Z_T=\frac{1-k(M-1)}{2M}\,Z_T \tag{21a}$$

$$\frac{Y'_T}{2M}+\rho Y_T=\frac{1-k(M-1)}{2M}\,Y_T \tag{21b}$$

for the series-element and shunt-element terminations, respectively. The other elements are chosen as if for a uniform network but with the series (or respectively shunt) elements each increased by the factor $(1+k)$.

It has been found possible to modify the terminations of a uniform ladder network to make it electrically more symmetrical in B and C (that is, the distinction between shunt-element and series-element termination is reduced) and electrically more nearly like its corresponding circuit of distributed characteristics, both effects being true only over a limited range of frequencies. Since the frequency range is independent of the number of sections and the improvements are small, the results are probably not of great practical importance. However, some improvement was found of a magnitude sufficient to make the new termination of value in an experimental application in which only a few sections are used. With many sections the need for accuracy would have to be extreme to make the new terminations useful.

In the discussion, emphasis has been placed on enhancing the similarity between the lumped network and a smooth line. Z_T and Y_T each can have any form, so any type of physical line is represented. Many forms of Z_T and Y_T, however, do not represent a realizable line at all. In such cases the electrical symmetry improvement, in the afore-mentioned sense, may be of some advantage.

In spite of the limitations on the practical value of the results, it is thought that they are worthwhile from the academic viewpoint alone. A theoretical survey is given, with definite proofs, of what can and cannot be done by varying both elements on each end of a uniform ladder network.

Appendix I

It is well known that only three of the four parameters of a 4-terminal network are independent and that when the network is symmetrical, only two are independent. The relation among them is well known[8] being, in our notation,

$$A^2-1=BC\alpha^2 \tag{22}$$

This is true for any symmetrical 4-terminal network, so the notation is perfectly general within that limitation. Expressing each side as a series in α^2 and carrying out the indicated multiplications give

$$a_0{}^2-1+2a_1a_0\alpha^2+(a_1{}^2+2a_0a_2)\alpha^4+\cdots = b_0c_0\alpha^2+(b_1c_0+c_1b_0)\alpha^4\cdots \tag{23}$$

Coefficients of like powers of α must be identical on the two sides so

$$a_0{}^2=1 \tag{24a}$$

$$2a_1a_0=b_0c_0 \tag{24b}$$

$$a_1{}^2+2a_0a_2=b_1c_0+c_1b_0 \tag{24c}$$

from which is obtained

$$a_0=1 \tag{25a}$$

$$a_1=\frac{b_0c_0}{2} \tag{25b}$$

These are generalizations of previous results making them applicable to any symmetrical network. It is seen that if $b_0=c_0=1$ and equations 25a–25b are substituted in equation 24c, the desired result, equation 11, is obtained. Equation 9 gives the necessary values for b_1 and c_1 for the case under consideration.

Appendix II

From a rearrangement of equation 14, one may write

$$6b_1=2\left(1-\frac{1}{2M^2}\right)\sqrt{1-\frac{M^2}{(2M^2-1)^2}}-1+\frac{1}{M^2} \quad (26)$$

The radical obeys the inequality

$$1-\frac{M^2}{2(2M^2-1)^2}-\frac{M^4}{2(2M^2-1)^4}<\sqrt{1-\frac{M^2}{(2M^2-1)^2}}<1-\frac{M^2}{2(2M^2-1)^2} \quad (27)$$

as will now be proved. The right-hand inequality is evident since the upper bound indicated is obtained if $M^4/4(2M^2-1)^4$ is added under the radical to form a perfect square. The writing of the proof for the left-hand half will be simplified if the letter W is used for the quantity $M/(2M^2-1)$. W^4 is greater than W^6 and W^8, because W is less than unity, so the following inequality may be formed:

$$\left(1-\frac{W^2}{2}-\frac{W^4}{2}\right)^2=1-W^2-\frac{3W^4}{4}+\frac{W^6}{2}+\frac{W^8}{4}<1-W^2-\frac{3W^4}{4}+\frac{W^4}{2}+\frac{W^4}{4}=1-W^2 \quad (28)$$

which is equivalent to the left-hand half of relation 27. The combination of formulas 26 and 27 yields a form which readily reduces to

$$1-\frac{1}{2(2M^2-1)}-\frac{M^2}{2(2M^2-1)^2}<6b_1<1-\frac{1}{2(2M^2-1)} \quad (29)$$

This is still too complex to be useful as an estimate, but it may be simplified by using the relations

$$2M^2-1=2\left(M^2-\frac{1}{2}\right)\geq 2M^2\left(1-\frac{1}{8}\right)=\frac{7M^2}{4} \quad (30a)$$

and

$$(2M^2-1)^2=2^2\left(M^2-\frac{1}{2}\right)^2\geq 2^2\left(M^2-\frac{1}{2}\right)^2\geq 2^2M^4\left(1-\frac{1}{8}\right)^2=\frac{49M^4}{8} \quad (30b)$$

which are true when $M\geq 2$. Using these, and the relation $2M^2-1<2M^2$, appropriately in inequality 29 we get

$$1-\frac{4}{14M^2}-\frac{8M^2}{98M^4}<6b_1<1-\frac{1}{4M^2} \quad (31)$$

Relation 15 follows directly from this.

Appendix III

The results of Appendix II, the fact that $b_1=c_1$, and the simple form for c_1 given in equation 12b allow estimates of ρ and $1-2\rho$ to be obtained with ease. Without giving the details of the algebra, it is found that

$$\frac{M^2-18/49}{M^2-1}<1-2\rho<\frac{M^2-1/4}{M^2-1} \quad (32a)$$

and

$$\frac{31/98}{M^2-1}<-\rho<\frac{3/8}{M^2-1} \quad (32b)$$

For convenient usage in the subsequent work, these may be replaced by the inequalities

$$\frac{M^2-2/5}{M^2-1}<1-2\rho<\frac{M^2-1/4}{M^2-1} \quad (33a)$$

and

$$\frac{3/10}{M^2-1}<-\rho<\frac{3/8}{M^2-1} \quad (33b)$$

which are nearly as good.

Now consider the formula for a_λ. From equations 4a–4c it is obvious that $c'_{\lambda-1}=2\lambda a'_\lambda$, which may be used to simplify the expression for a_λ to

$$a_\lambda=a'_\lambda(1-2\rho)^{\lambda-1}[1+2\rho(\lambda-1)] \quad (34)$$

When $\lambda=2$, this reduces to $a_\lambda=a'_\lambda(1-4\rho^2)$, which reduces to relation 18 when bounds of ρ are taken from inequality 33b. A general estimate may be obtained for $\lambda\geq 3$ by using both parts of relation 33 and whichever value of λ (3 or M) enhances the limit in question. This procedure yields inequality 19a.

Proceeding to the derivation of inequality 19b, we find complication because of the complexity of the expression for b_λ. From equations 4a–4c, it follows that $a'_\lambda=b'_\lambda\times(2\lambda+1)(2M^2)/(2M^2+\lambda)$, and $c'_{\lambda-1}=b'_\lambda\times(2\lambda)(2\lambda+1)(2M^2)/(2M^2+\lambda)$. These, when substituted in equation 8b, yield

$$b_\lambda=b'_\lambda(1-2\rho)^{\lambda-1}\left\{(1-2\rho)^2+[\rho^2(2\lambda+1)\times(2\lambda)+2\rho(1-2\rho)(2\lambda+1)]\frac{2M^2}{2M^2+\lambda}\right\} \quad (35)$$

An upper bound of b_λ will first be found. The first term in the brackets is positive and the second is negative. This necessitates the use of upper bounds for all components of the former and lower bounds for all components of the latter. Since $2M^2/(2M^2+\lambda)$ is a factor of each, it is subject to this general statement in its two roles as a multiplier. Satisfactory upper and lower bounds for $-\rho$, ρ^2, and $1-2\rho$ are given in relations 33. When $2M^2/(2M^2+\lambda)$ multiplies the first term, it may be replaced by 1, while in the other case it may be replaced by the lower bound $M/(M+1)$. Also $(2\lambda+1)(2\lambda)$ is less than $(2M+1)(2M)$, and $(2\lambda+1)\geq 5$ if $\lambda\geq 2$. Omitting the details of the algebra, it is found that

$$b_\lambda<b'_\lambda\frac{(M^2-1/4)^{\lambda-1}}{(M^2-1)^{\lambda+1}}\left(M^4-2M^2-\frac{15M^2}{16}+\frac{105M}{32}+\frac{1}{16}\right) \quad (36)$$

When $M\geq 4$ the quantity represented by the three terms on the right of the above parenthesis is less than one, so if this restriction is imposed on M, the entire parentheses on the right may be replaced by $(M^2-1)^2$, which conveniently cancels against part of the denominator, leaving

$$b_\lambda<b'_\lambda\left(\frac{M^2-1/4}{M^2-1}\right)^{\lambda-1} \quad (37)$$

The upper bound is treated in a similar fashion. When $\lambda\geq 2$, the quantity $(2\lambda+1)\times(2\lambda)$ may be replaced by the lower bound 20; in the other term $(2\lambda+1)$ may be replaced by the upper bound $(2M+1)$; and $2M^2+(2M^2+\lambda)$ may be replaced by the upper and lower bounds 1 and 1/2 in appropriate locations. Proceeding as before, one obtains, after simplifications,

$$b_\lambda>b'_\lambda\frac{(M-2/5)^{\lambda-1}}{(M^2-1)^{\lambda+1}}\left(M^4-\frac{3M^2}{2}-\frac{31M^2}{20}+\frac{3M}{8}+\frac{499}{400}\right) \quad (38)$$

When $M\geq 4$, the expression in the parentheses on the right is greater than $M^4-2M^2+2M-1=(M-1)^2(M^2-1)$, which if substituted cancels partially against the denominator to yield

$$b_\lambda>b'_\lambda\left(\frac{M-2/5}{M^2-1}\right)^{\lambda-1}\left(\frac{M-1}{M+1}\right) \quad (39)$$

Inequalities 37 and 39 combine to give inequality 19b.

Recalling the formula for c_λ, we see that it already is taken care of by the estimate of $1-2\rho$. Relation 19c follows directly.

Appendix IV

It is evident from the analysis leading up to equation 13 that b_1 and c_1 each cannot be equal to 1/6. However, one might suppose that b_1 and c_1 could be given errors of opposite sign to make $b_1+c_1=1/3$. Writing this out from equations 8b–8c, we obtain

$$\rho(1-2\rho)+\frac{1}{6}\left(1+\frac{1}{2M^2}\right)(1-2\rho)^2+\rho^2+\frac{1}{6}(1-2\rho)\left(1-\frac{1}{M^2}\right)=\frac{1}{3} \quad (40)$$

the solution of which is

$$\rho^2=-\frac{1}{4(M^2-1)} \quad (41)$$

The indicated imaginary value for ρ is physically impossible using passive elements because it must hold over a range of frequencies.

Let us now find the condition on ρ that will give a minimum error in a_4. At such a value the derivative of b_1+c_1 with respect to ρ will be zero. Differentiating the left side of equation 40 and setting the result equal to zero give, after reduction,

$$\frac{2\rho}{3}\left(\frac{1}{M^2}-1\right)=0 \quad (42)$$

Since $M=1$ never occurs, the solution is $\rho=0$. It is evident, since there is only one root and since the error can never be zero, that

this corresponds to a minimum and not a maximum error.

Appendix V

The analysis for the changing of two elements on each end of the network will proceed with reference to the circuit of Figure 4. This is built up by starting with the mid-shunt terminated network between lines P-P, with a subsequent double application of the modification principle already described in the text. The original network has a total impedance and admittance, respectively, of Z'_T and Y'_T. We first add a shunt element of magnitude $\beta Y_T{}^*$, where $Y_T{}^*$ will indicate the new total admittance. The transformation, in similarity with equations 5a–5d, involves the quantities

$$\alpha^* = \sqrt{Z_T{}^* Y_T{}^*} \tag{43a}$$

$$Z'_T = Z_T{}^* \tag{43b}$$

$$Y'_T = (1-2\beta) Y_T{}^* \tag{43c}$$

$$\alpha' = \alpha^* \sqrt{1-2\beta} \tag{43d}$$

As has been pointed out in the text, equations 8a–8c will give the coefficients for the new circuit if the equations for b_λ and c_λ are interchanged, due attention being given to differences in notation. Specifically, a_λ, b_λ, and c_λ become, respectively, $a_\lambda{}^*$, $c_\lambda{}^*$, and $b_\lambda{}^*$, while a'_λ, b'_λ, and c'_λ still are given by equations 4a–4c. The circuit between the lines Q-Q is then in a condition to receive a series element on each end, giving it the appearance of a modified mid-series terminated network. Let the added element on each end be σZ_T, and let the following additional notational changes take place:

$$\alpha = \sqrt{Z_T Y_T} \tag{44a}$$

$$Z_T{}^* = (1-2\sigma) Z_T \tag{44b}$$

$$Y_T{}^* = Y_T \tag{44c}$$

$$\alpha^* = \alpha \sqrt{1-2\sigma} \tag{44d}$$

Equations 8a–8c again may be applied, this time as they stand, with a'_λ, b'_λ, and c'_λ replaced by the corresponding starred coefficients. Thus, unprimed coefficients apply to the over-all circuit of Figure 4. For simplicity of notation, M-1 will be replaced by N until the results are achieved. It will be necessary to consider only the four coefficients b_0, b_1, c_0, and c_1, which, as derived by the foregoing plan of action, are

$$b_0 = 2\sigma a_0{}^* + b_0{}^* (1-2\sigma) = 1 \tag{45a}$$

$$b_1 = 2\sigma(1-2\sigma) a_1{}^* + (1-2\sigma)^2 b_1{}^* + \sigma^2 c_0{}^* = a(1-2\sigma) + (1-2\sigma)^2 (1-2\beta) c'_1 + \sigma^2 \tag{45b}$$

$$c_0 = c_0{}^* = 1 \tag{45c}$$

$$c_1 = (1-2\sigma) c_1{}^* = (1-2\sigma)[2\beta a'_1 (1-2\beta) + b'_1 (1-2\beta)^2 + c'_0 \beta^2] \tag{45d}$$

The simplifications which already have been included in the writing of these equations come from the facts that $a_0{}^* = b_0{}^* = c_0{}^* = 1$, and $a_1{}^* = 1/2$, in similarity with equations 9 and 10. Since the correctness of b_0 and c_0 assures the correctness of a_1, as before, our attention may be confined to b_1 and c_1. The algebraic work may be expedited by changing the notation to

$$x = 1-2\beta \tag{46a}$$

$$y = 1-2\sigma \tag{46b}$$

The reduced formulas for b_1 and c_1 are obtained by taking a'_1, b'_1, c'_0, and c'_1 from equations 4a–4c, with M replaced by N. This gives

$$b_1 = \frac{1}{4} - \frac{y^2}{4} + \frac{1}{6}\left(1 - \frac{1}{N^2}\right) x y^2 \tag{47a}$$

$$c_1 = \left[\frac{1}{4} - \frac{1}{12}\left(1 - \frac{1}{N^2}\right) x^2\right] y \tag{47b}$$

We first will see if b_1 and c_1 each can be made equal to 1/6, or at least if their sum can be 1/3 so that a_1 will be correct. Accordingly, assume $b_1 = 1/6 + \epsilon$ and $c_1 = 1/6 - \epsilon$, which represents both conditions, since ϵ may be zero. The result of these substitutions and the subsequent combination of equations 47a–47b is a quadratic in ϵ, as follows:

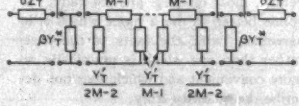

Figure 4. Two-element modification

$$144 G \epsilon^3 + (12F - 48G)\epsilon + (4G - F) = 0 \tag{48}$$

where

$$G = G(N, x) = 3 - 2\left(1 - \frac{1}{N^2}\right) x \tag{49a}$$

$$F = F(N, x) = 9 - 6\left(1 - \frac{1}{N^2}\right) x^2 + \left(1 - \frac{1}{N^2}\right)^2 x^4 \tag{49b}$$

The discriminant of equation 48 is easily computed to be $144F(F-4G)$. It must be positive if a real solution is possible, so we are interested in

$$F - 4G = \left(\frac{N^2-1}{N^2}\right)\left(\frac{N^2-1}{N^2} x^4 - 6x^2 + 8x - \frac{3N^2}{N^2-1}\right) = \frac{N^2-1}{N^2} H(N, x) \tag{50}$$

Before investigating the positiveness of $H(N, x)$, it should be noted that to have a physically realizable circuit it is necessary that $-1/2(N-1) < \delta < 1/2$. Outside of this range the end shunt elements either would vanish completely, thus changing the number of network sections, or would be greater than half the total admittance. The corresponding range of x is $0 < x < N/(N-1)$. If $H(N, x)$ is computed for $N = \infty$ throughout the largest possible range of x, it will be found to be everywhere nonpositive. Furthermore, as may be easily shown, $\partial H \times (N, x)/\partial N$ is always positive, so $H(N, x)$ is less than $H(\infty, x)$ and is therefore always negative in the pertinent range. Thus there is no real solution of equation 48, so b_1 and c_1 cannot be real and also have 1/3 as their sum.

Following a procedure similar to that used in the simpler case, we next investigate whether the error in a_2 can be made a minimum. The total differential of $b_1 + c_1$ is

$$d(b_1 + c_1) = \left(\frac{\partial b_1}{\partial x} + \frac{\partial c_1}{\partial x}\right) dx + \left(\frac{\partial b_1}{\partial y} + \frac{\partial c_1}{\partial y}\right) dy \tag{51}$$

The smallest possible error will occur when dx and dy are independent and thus when their coefficients are each zero. As may be seen easily by carrying out the necessary differentiation, equating the coefficient of dx to zero gives

$$\frac{1}{6}\left(1 - \frac{1}{N^2}\right)(y^2 - xy) = 0 \tag{52}$$

from which one obtains the condition $y = x$, since $N \neq 1$. With the substitution of x for y in the derivatives of the coefficient of dy, the setting of this equal to zero gives

$$x^3 - \frac{2N^2}{N^2-1} + \frac{N^2}{N^2-1} = \left(x - \frac{N}{N-1}\right) \times \left(x - \frac{N}{N+1}\right) = 0 \tag{53}$$

The $N/(N-1)$ solution gives a value of β which wipes out the shunt element on each end and is found to correspond to a maximum error. The other solution gives $\beta = 1/2(N+1)$. The corresponding complete end element is $Y_T[(1-2\beta)/2N + \beta] = Y_T/(N+1) = Y_T/M$. This means that all shunt elements will be the same. Also, the series element is $\sigma Z_T = \beta Z_T$, since $y = x$, which gives the value $Z_T/2M$, which is a mid-series termination. This should have been expected, since the case for uniform shunt elements has already been treated.

Now suppose we make $b_1 = c_1$. This makes y and x interdependent, so dy and dx in equation 51 are no longer independent. Also, since b_1 and c_1 are to be equal as x and y vary, it is only necessary to take the derivative of one of them. dy/dx may be obtained from the implicit function $b_1 - c_1 = 0$ as

$$\frac{dy}{dx} = -\frac{\partial(b_1 - c_1)/\partial x}{\partial(b_1 - c_1)/\partial y} \tag{54}$$

Thus

$$\frac{db_1}{dx} = \frac{\partial b_1}{\partial x} + \frac{\partial b_1}{\partial y}\frac{dy}{dx} = \frac{\frac{\partial b_1}{\partial x}\left(\frac{\partial b_1}{\partial y} - \frac{\partial c_1}{\partial y}\right) - \frac{\partial b_1}{\partial y}\left(\frac{\partial b_1}{\partial x} - \frac{\partial c_1}{\partial x}\right)}{\frac{\partial b_1}{\partial y} - \frac{\partial c_1}{\partial y}} \tag{55}$$

The denominator of equation 55 cannot be infinite, so we set the numerator equal to zero, giving, after reduction,

$$-\frac{\partial b_1}{\partial x}\frac{\partial c_1}{\partial y} + \frac{\partial b_1}{\partial y}\frac{\partial c_1}{\partial x} = 0 \tag{56}$$

The substitution of the expressions for these derivatives gives an equation from which y can be eliminated. The remaining equation in x is identical with equation 53. Thus $x = N/(N+1)$ is again the solution, but of course y is no longer equal to x. It is not necessary to compute y because it has been

Geometric Mean Distances for Rectangular Conductors

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THE USE of geometric mean distance for calculating reactance of parallel conductors is increasing, so much so that the self geometric mean distance often is tabulated in catalogs of heavy conductors along with other characteristics, such as resistance, current capacity, and weight.

The logarithm of the geometric mean distance between two areas or cross sections is defined as the average of the logarithms of all possible distances from points on one area to those on the other, and the logarithm of the self geometric mean distance of an area is the average of the logarithms of all possible distances between two points on the area.[1]

The inductance, as computed by the geometric mean distance method, is the inductance at zero frequency. Metal of uniform conductivity, such as copper, is taken to have constant current density, or more generally, the current in a conductor is taken to be proportional to the conductance of that conductor, as it would be with direct current.

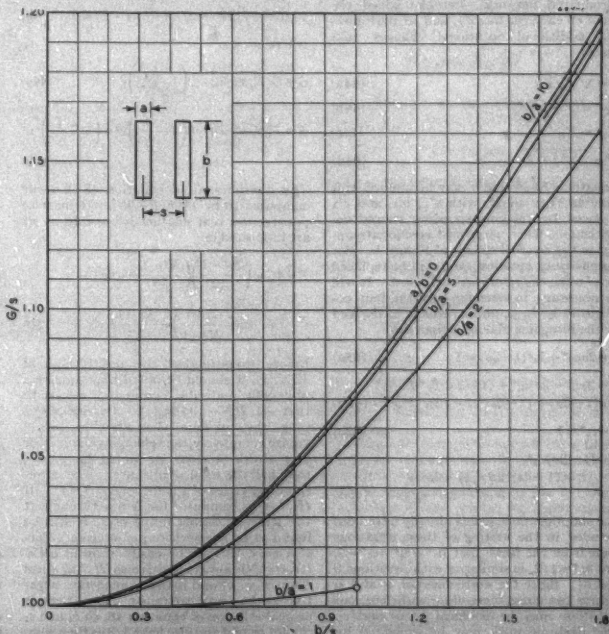
The self geometric mean distance of an area is sometimes called the geometric mean radius of the area, although it is not a radius nor an average of radii. It is, as the definition states, the mean distance (geometric, as distinguished from arithmetic) of all possible distances between two points on the area, and of course, most of these are not radii. It seems better to use a name which is in agreement with the facts of the case, rather than one which is practically no more convenient and which does not describe the quantity truly.

Formulas for the geometric mean distance of geometrical shapes can be obtained by a process of integration.[1] However, the formula for two rectangles, even when the problem is simplified by specifying two duplicate rectangles placed opposite each other, fills half a page. For engineering purposes, curves of reactance values for rectangular conductors can be used.[2] See also Tables I–III in a paper published in 1929 by Professor F. W. Grover.[3]

In this paper are given curves for geometric mean distance between rectangular areas which will give a somewhat more direct solution for general types of problems, such as those involving polyphase circuits or conductors in parallel.

In circuits or portions of circuits where the parallel conductors are not transposed, the reactive voltage drop in the various conductors is different. It may be computed by counting flux caused by each conductor, up to a certain large distance u. In a complete system of parallel conductors in the steady state, the sum of all the currents is zero, that is there is as much return current as going current in the group. The quantity u cancels out as it is associated with all of the conductors in turn (see equation 2). Therefore, the result is the same,

Figure 1. Geometric mean distance of rectangular areas, face-to-face position



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shown that when x has this value the shunt elements are all uniform. This means that the determining of y is equivalent to the finding of ρ in the problem as originally treated.

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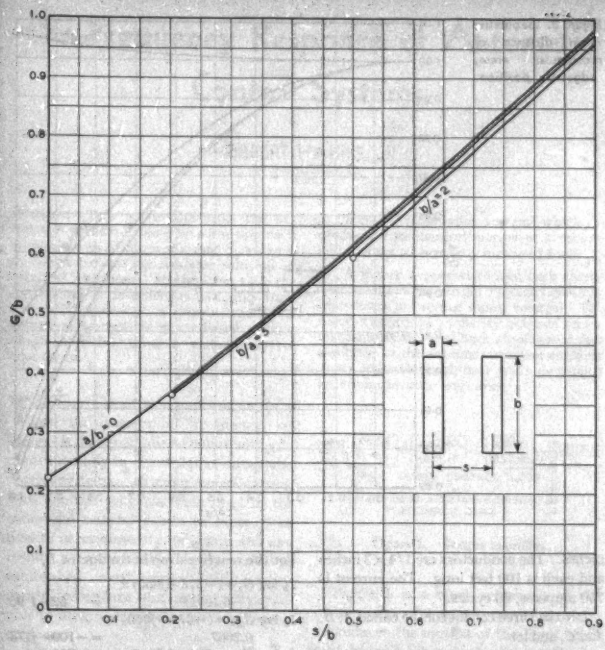


Figure 2. Geometric mean distance of rectangular areas, face-to-face position, close spacing

no matter how large u may be. The currents, as well as the conductor arrangement, may be unbalanced or balanced and are in amperes.

If R_A is the resistance per centimeter of conductor A of a group of long parallel conductors A, B, C, . . ., if G_{AA} is its self geometric mean distance, if G_{AB} is the geometric mean distance of the section of A from that of B, and so forth, the voltage drop in conductor A is

$$I_A R_A + j4\pi f \times 10^{-9}\left[I_A \log_e \frac{u}{G_{AA}} + I_B \log_e \frac{u}{G_{AB}} + I_C \log_e \frac{u}{G_{AC}} + \ldots\right] \text{ volts per centimeter} \quad (1)$$

where f is the frequency. Putting

$$(I_A + I_B + I_C + \ldots) \log_e u = 0 \quad (2)$$

u being a finite constant, although as large as desired, we have the reactive voltage drop in conductor A:

$$= -j4\pi f \times 2.303 \times 10^{-9}[I_A \log_{10} G_{AA} + I_B \log_{10} G_{AB} + I_C \log_{10} G_{AC} + \ldots] \text{ volts per centimeter} \quad (3)$$

or

$$= -j0.0529[I_A \log_{10} G_{AA} + I_B \log_{10} G_{AB} + I_C \log_{10} G_{AC} + \ldots] \text{ volts per 1,000 feet at 60 cycles} \quad (4)$$

Note that A, B, and C necessarily do not mean different phases, but merely different conductors.

Equations 3 and 4 are general formulas for the reactive voltage drop in any one of a group of long parallel conductors whose currents are given. The conductors may be of different phases or they may be branches in parallel.

The self geometric mean distance of a rectangular sectional area $a \times b$ is given within 0.13 per cent by the formula

$$G_s = 0.2234(a+b) \quad (5)$$

Actually, the numerical term varies from 0.2231 to 0.2237 for different ratios of a to b.[4]

The geometric mean distance between two equal rectangular areas, placed opposite each other with the sides parallel, may be read from the curves shown in Figures 1, 2, or 3, depending on the ratios of the dimensions. For the use of these curves see the examples.

The geometric mean distance between two equal rectangular areas, placed obliquely and not very close together, may be taken as the distance between their centers for a first approximation. The percentage error resulting from this procedure may be estimated by reference to Figures 1 and 3. For instance, if the distance between centers of two comparatively thin straps is 1.25 times the strap width, then from Figure 1, for the parallel plane position, $b/s = 0.8$ and G is five per cent greater than s. From Figure 3, for the edgewise position, $a/s = 0.8$ and G is six per cent less than s. Then for an oblique position, with the afore-mentioned distance between centers, the error in taking $G = s$ may be expected to be numerically less than plus or minus six per cent. However, this result does not mean six per cent error in reactance, since log G is involved.

In either equation 3 or 4, the distances G_{AA}, G_{AB}, G_{AC} . . . may be all in centimeters or all in inches (or in feet), so long as they are all in the same unit.

When there is complete transposition so that each conductor occupies all the positions in succession to an equal extent, the geometric mean distance method may be extended to give a convenient calculation for the average voltage drop. For this calculation, values of geometric mean distance of rectangles taken from Figures 1, 2, and 3 are useful, as well as in problems where equations 3 and 4 are used.

Precise values of $\log_e$ geometric mean distance are given for equal squares in many relative positions.[5] By combining these squares into rectangles of various shapes and positions, the precise value of the logarithm of the geometric mean distance was computed for a considerable number of cases of rectangles opposite each other. From these determinations and from values of G_s (equation 5), reactance values in micro-ohms per foot at 60 cycles were obtained. Formulas for infinitely thin rectangular conductors, that is for $b/a = 0$ and $a/b = 0$, are given[4] and curves of reactance values were plotted.[3]

In the present paper, instead of values of loop reactance, values of the geometric mean distances themselves are plotted. Their use has been described and is illustrated in the examples. For these curves a number of additional values have been determined.

Example 1

Find the reactive voltage drop in a single-phase ventilated bus bar circuit made up of four straps of size 1/8 by 3 inches, side by side in vertical planes. Each bus bar consists of two straps at $\frac{1}{8}$ inch centers. The distance between centers of bus bars is $2\frac{1}{8}$ inches. The cur-

rent of the circuit is 900 amperes, 60 cycles.

Let the four straps be called A, B, C, and D. Then the center-to-center distance from A to B is $^1/_2$ inch, 2 inches from B to C, and $^1/_2$ inch from C to D. A and B are connected in parallel. Neglecting circulating currents, A and B will each carry +450 amperes, and C and D each −450 amperes.

For computing the voltage drop in A by equation 4, using logarithms to base 10,

$G_s = 0.2234 \times 3.125 = 0.698$ inch
$\log 0.698 = \bar{1}.8439 = -0.1561$

For G_{AB},

$s/b = 0.5/3 = 0.167$, $b/a = 24$

From Figure 2,

$G_{AB} = 0.343 \times 3.0 = 1.029$
$\log 1.029 = 0.01242$

For G_{AC},

$b/s = 3/2.5 = 1.20$

From Figure 1,

$G_{AC} = 1.101 \times 2.5 = 2.752$
$\log 2.752 = 0.4396$

Alternatively, by Figure 2,

$G_{AC} = 0.917 \times 3 = 2.751$

Similarly,

$\log G_{AD} = 0.508$
$I_A \log G_s = 450 \times (-0.1561) = -70$
$I_B \log G_{AB} = 450 \times 0.01242 = +6$
$I_C \log G_{AC} = -450 \times 0.439 = -198$
$I_D \log G_{AD} = -450 \times 0.508 = -228$
$-496+6$
$-496+6 = -490$

By equation 4, the reactive drop in A for 70 feet is

$j\,0.0529 \times 490 \times 0.070 = j\,1.81$ volts

In a similar way, the drop in B is found to be

$-j\,0.0529 \times 0.070(-70+6-163-198) = j\,1.57$ volts

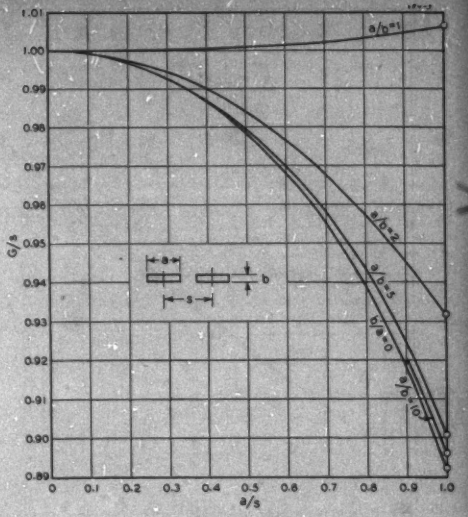
The difference in these computed voltage drops in A and B may be said to result in an unbalance of current, which may be computed if desired.

The result of this problem agrees with the results of previously computed problems.[2]

Example 2

Find the reactive drop in each conductor of a 3-phase circuit consisting of three rectangular conductors (one conductor per phase) in parallel planes, the distance between centers being $1^1/_2$ inches. The conductors are 1/4×3 inches and each is 100 feet long. The current is 750 amperes, 60 cycles.

Figure 3. Geometric mean distance of rectangular areas, edgewise position



Let the three conductors be called A, B, and C, and let

$I_A = 750$ amperes
$I_B = 750(-0.5+j\,0.866)$ amperes
$I_C = 750(-0.5-j\,0.866)$ amperes

By equation 5,

$G_s = 0.2234\ (0.25+3) = 0.726$ inch
$\log 0.726 = \bar{1}.8609 = -0.1391$, omitting the subscript 10 in $\log_{10}$

For G_{AB},

$s/b = 1.5/3 = 0.5$, $b/a = 12$

From Figure 2,

$G_{AB} = 0.616 \times 3.0 = 1.848$ inches
$\log 1.848 = 0.2667$

For G_{AC},

$b/s = 3/3 = 1$, $b/a = 12$

From Figure 1,

$G_{AC} = 1.072 \times 3.0 = 3.216$ inches
$\log 3.216 = 0.5073$
$I_A \log G_s = 750(-0.1391) = -104$
$I_B \log G_{AB} = (-375+j650) \times 0.2667 = -100+j173$
$I_C \log G_{AC} = (-375-j650) \times 0.5073 = -190-j330$
$-394-j157$

By equation 4, the reactive drop in A for 100 feet is

$-j\,0.0529 \times 0.10(-394-j157) = -0.83+j2.09$ volts $= 2.24$ volts

For the reactive drop in conductor B,

$I_B \log G_s = (-375+j650) \times (-0.1391) = 52-j\,90$
$I_C \log G_{BC} = (-375-j650) \times 0.2667 = -100-j173$
$I_A \log G_{AB} = 750 \times 0.2667 = 200$
$152-j263$

By equation 4, the reactive drop in B is

$-j\,0.0529 \times 0.10(152-j263) = -1.40-j\,0.81 = 1.62$ volts

The reactive drop in conductor C has the same numerical value, 2.24 volts, as in A.

The result of this problem agrees with already proved similar problems.[3]

It is a little more straightforward to use geometric mean distances and equation 4 as in this paper, than to rearrange the problem so as to use reactance values of single loops. The geometric mean distance method is applicable also to a wide range of reactance problems.

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The Frequency Response of Automatic Control Systems

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Synopsis: This paper illustrates the advantages of the frequency response approach to the analysis of automatic control systems, as contrasted to the analytic solution of transient responses. At the same time the equivalence of information available from the two approaches is demonstrated. A numerical example is given based upon a torque amplifier using a motor-generator type control.

THE purpose of this paper is to show how the concept of frequency response is being applied analytically and experimentally in the design of automatic control systems such as servomechanisms. This concept long has been used in the radio and telephone arts to express the fidelity of response of equipment, and as a result a considerable background of established mathematics and experimental procedure has been made available to instrument and automatic control engineers.

A transient analysis of the response of an automatic control to some standard type of disturbance is an accepted procedure, but with the more complex systems it becomes unwieldy, and useful design criteria become increasingly difficult to develop. A frequency analysis based on the mathematics of the Fourier series and the Fourier integral provides information equivalent to the transient analysis but with much less calculation and with more easily interpretable results. This paper will show this equivalence and the mathematical procedures involved in the design of a servomechanism.

Typical Servomechanisms

A servomechanism is a system in which some variable quantity is controlled to follow a definite function of some other varying quantity. Typical servomechanisms are

1. A self-balancing potentiometer[1] in which the controlled variable is the mechanical position of the pen and slide wire, and the desired position is proportional to the varying quantity, namely the voltage under measurement.

2. A machine tool pattern follower for which the controlled variable is the tool position, and the desired position is proportional to the varying shape of the pattern as the tool moves along.

3. A data transmission system[2] which reproduces a mechanical motion at a remote point, often with greatly increased force.

4. A highly degenerative feed-back amplifier[3] in which the output voltage faithfully reproduces a varying input voltage. The recognition of the similarity between servomechanisms and feed-back amplifiers makes available to the automatic control engineer many valuable analytical tools developed by communication engineers.

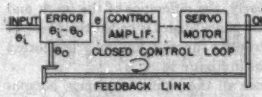

Figure 1. Torque amplifier

Figure 1 is a block schematic of the components of a torque amplifier which reproduces the motion of the input shaft and drives a heavy load, without placing any appreciable load on the input shaft. The load is driven by a motor controlled by a signal or motion from a device which measures the difference or error between the input and output shafts. This error-measuring device is the only load on the input shaft and may be made quite light. All of the examples listed are similar in that they all comprise an input, an output, an error-measuring device, an amplifier, and a power unit which drives the load to bring the error to zero.

The Transient Analysis

All systems which take the form of a closed loop as in Figure 1 have a tendency to be unstable and hunt, or at least to perform damped oscillations about their zero error position. The first problem in proper servomechanism design is to minimize these oscillations after any transient disturbance. The second problem of proper design is to minimize errors which occur under steady conditions, such as a constant velocity or acceleration motion of the input shaft, and errors caused by the loads on the output shaft. Usually the solution must be a compromise between the best solutions for these two problems.

One procedure for studying the oscillatory character of a system analytically is to assume a motion for the input and then calculate the resultant transient response of the output. A typical input is a suddenly applied constant velocity as is shown in Figure 2 along with a typical resulting output motion.

With the assumption that the system is linear over the region under investigation, any one of several classical, operational, or transform methods[4] for solving linear differential equations with constant coefficients may be used for calculating such a transient response. Whatever method is used, there are four essential steps in the solution.

1. The differential equations for the system are set up.

2. The characteristic equation of the above set is obtained. This equation has the form

$$a_n p^n + a_{n-1} p^{n-1} + \ldots a_1 p + a_0 = 0$$

in which the coefficients contain the various parameters of the system, such as amplifier gain, inertia, friction, and circuit constants.

3. The characteristic equation is solved for its roots. The roots will be real or in conjugate complex pairs. $p_n = \sigma_n \pm j\omega_n$

4. The final solution contains a term of the form $Ae^{\sigma t}\cos(\omega t + \alpha)$ for each complex root, an exponential term for each real root, and a particular solution which depends on the input motion. The coefficients A and phase angles α will depend upon the initial conditions of the system.

In this solution the rate of decay of the oscillatory terms is determined by the real parts of the complex roots, namely the σ_n's. If these are large and negative, the oscillations will damp quickly. If one is small, then the damping will be slow. If any one is positive, the system will be unstable and oscillations will increase.

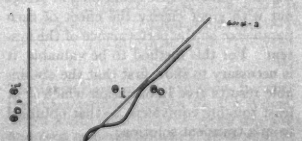

Figure 2. Transient response to an input velocity

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The solution of the characteristic equation is the key point in all the methods of transient analysis. If the degree n is five or more, only a numerical solution may be obtained and then only by such laborious calculations that an engineer often cannot afford the necessary time. This situation is accentuated by the fact that even after a solution is found there is often no feasible way to tell what parameters must be changed to improve the system because the system parameters are so completely intermixed in the coefficients a_n. A later illustration will bring out this point.

Stability Criteria

Instead of solving the characteristic equation, a compromise often is resorted to which merely tells whether the system is stable or unstable. Hurwitz or Routh criteria[4] when applied to the coefficients a_n will tell whether there are any roots with positive real parts. This may be an unsatisfactory compromise, since many stable systems damp very slowly and the stability criteria do not show what changes are needed for improvement.

The System Transfer Function

The frequency response method of analysis eliminates the necessity for solving the characteristic equation and brings out with great clarity the effect of each parameter on the performance of the system. For this method to be valuable, it is necessary to show first that the obtainable results give information which is at least roughly equivalent to that obtained from a transient solution.

Consider the input and output motions as shown in Figure 2. The transient completely dies out after a certain period of time, and if a new similar disturbance is introduced after this time, the response will repeat. This may be repeated again and again so that the input and the response will appear as in Figure 3. As is well known, both of these periodic time functions may be analyzed into a Fourier series of sinusoidal terms of frequencies which are multiples of $1/T$. By including a sufficient number of terms in the series, the motions may be approximated arbitrarily closely.

Corresponding to each sinusoidal term which is a component of the input motion there is a term of the same frequency which is a component of the output motion. The two corresponding terms at each frequency will differ in amplitude and in phase angle between the input and the output. The ratio of the output amplitude to the input amplitude is known as the magnitude of the system transfer function, and since it is a function of frequency, it may be plotted as in Figure 4. Similarly, the difference of the input and output phase angles is called the phase of the transfer function and may be plotted also as in Figure 4.

Since all the input frequency components add together to form the input transient and all the output components add together to form the output transient, the transfer function which tells how these components are modified must contain all the information available from the system differential equation. The proper interpretation of curves such as those in Figure 4 will yield this information. This interpretation is discussed immediately following, while the calculating procedure is deferred until later.

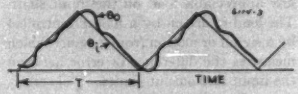

Figure 3 (above). Response to a periodic input

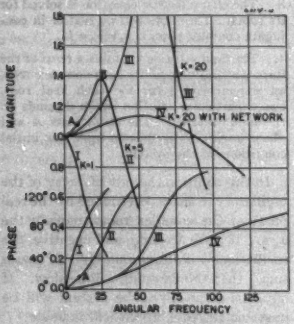

Figure 4 (left). System transfer functions

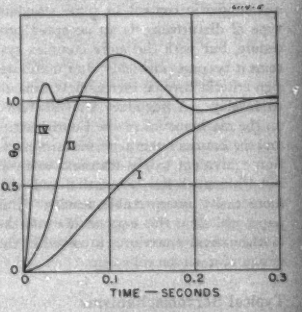

Figure 5 (right). Response to a unit step input

Interpretation of the Transfer Function

The ideal transfer function from the standpoint of perfect following of the input would be one which does not in any way change the components. This would occur with a magnitude of unity and a phase difference of zero over the whole frequency range. Actual transfer functions differ from the ideal in three important aspects.

1. Certain frequencies are accentuated or amplified as illustrated by the frequencies near $\omega = 25$ radians per second for curve II of Figure 4. This peaking of these frequencies is called resonance. A transient disturbance will result in a damped oscillation at a frequency near the resonant frequency as shown in a corresponding transient response curve, II of Figure 5. There is a correlation between the height of the resonance peak and the time required for the transient oscillation to die out, but it is not generally expressible in quantitative form.

The allowable height of a resonance peak can be specified only from experience with systems of similar application, but this is also true of any specification of desired damping for a transient response. For data transmission systems such as the one described below, a peak of about 1.2 is a good maximum value for high performance systems, but peaks as high as 1.5 are sometimes acceptable.

2. The higher frequencies always are attenuated; that is, the magnitude of the transfer function approaches zero as the frequency is increased. This results in the output being more or less sluggish and less harp than the input motion. This is illustrated by curves I and IV of Figures 4 and 5. The system which passes more of the high frequencies has the faster motion. Two systems which have exactly the same form of transfer function but with different frequency scales will have exactly the same form of transient response but with a time scale which is inverse to the frequency scale. Thus, by doubling the frequency response of a system the transient response time is halved.

Another aspect of the frequency bandwidth concept is that the usual input motions predominate in low frequencies. For example, even in the unattainable periodic square wave of position in which the input periodically jumps forward a certain amount and then back, the amplitude of the frequency components drops off as $1/\omega$. For a periodically positive and negative velocity which is less sharp, the amplitudes drop off

as $1/\omega^2$, and for a periodically positive and negative acceleration, the amplitudes are proportional to $1/\omega^3$.

Since most input motions predominate in the low frequencies, more attention should be paid to the behavior of the transfer function at low frequencies. As an example, a resonance peak at a high frequency acceptably may be somewhat greater than a peak at a low frequency, since it is less likely to be excited. Similarly, it is preferable to have a good phase function, as discussed below, at low frequencies rather than high ones if a choice must be made.

Sometimes it is desirable to use a servomechanism as a filter to remove from the output motion certain bands of frequencies which are present in the input. A common filter removes high frequency noise from the input, and this then determines the band of frequency response.

3. The phase characteristics as in Figure 4 also carry information concerning the response of a system, since the phase lag may be considered as a time delay for each component. In general, the best response is obtained with a system which has the least phase lag in the transfer function, particularly at the lower frequencies.

One important phase characteristic to recognize is the case for which the phase lag is proportional to frequency. In this case, since each component will be delayed by a time,

$$t_D = \frac{\text{phase lag in radians}}{\text{angular frequency in radians per second}}$$

all components will be delayed equally, and therefore the complete transient response will be delayed by a time t_D. A special case of this occurs when the servomechanism is following a constant velocity input at speed n; then the lag in following, after transients have died out, will be (nt_D) where t_D is the slope of the phase curve near zero frequency.

While it is often convenient to consider the phase functions in the interpretation of the transfer function, it is not absolutely necessary since there is a definite relationship between the phase and magnitude functions, as later discussion will show.

Electrical Torque Amplifier

While these criteria for good frequency response are quite qualitative in nature, they do provide a basis for the comparison of servomechanisms, and, more important, they provide a powerful aid in thinking about the various factors that can produce stability or instability in a system. This will be illustrated by an analysis of the torque amplifier of Figure 1, which is detailed in Figure 6.

The motor drive for the torque amplifier consists of a d-c motor and a controllable motor generator set. The servomotor has a constant field excitation and its armature voltage is supplied from the motor generator set. The generator is driven at constant speed, and its fields are in the output circuit of an amplifier which varies the excitation and therefore the generated voltage.

The amplifier is of the d-c type and has a push-pull output stage arranged so that the field flux is proportional to the output unbalance, which in turn is proportional to the input. Inductance in the field circuit prevents a sudden change in input voltage from producing a sudden change in field flux. This inductance and the consequent delay will have an effect on the stability of the system.

A network, often called a lead or derivative network, is included in the amplifier circuit for the purpose of stabilizing the system and improving its response, as later analysis will show.

The device for measuring the error between the input and output may, for example, be a reluctance type of bridge which provides an alternating voltage proportional to the error without placing an appreciable load on the input shaft. A direct voltage is obtained proportional to the error by means of a phase-sensitive detector, and a simple RC type filter is included to filter the detector output. The filter also will have an effect on the servo stability.

Analytical Derivation of the System Transfer Function

The most straightforward, but a tedious, procedure for the calculation of the transfer function is summarized as follows:

1. Set up the linear differential equations for the system.

2. Replace each derivative dx/dt by px and each integral $\int x dt$ by x/p just as in the transient solution and then solve the resulting set of simultaneous equations for the output-to-input ratio. For the system detailed in Figure 6 and with symbols given in the accompanying list, this expression comes out as

$$\frac{\theta_o}{\theta_i} = \frac{K(1+A_3p)}{\left\{\begin{array}{l} K+p(KA_3+f+g)+p^2[J+ \\ \quad (f+g)(B_1+B_2+B_3)]+p^3[J(B_1+ \\ \quad B_2+B_3)+(f+g)(B_1B_2+B_2B_3+ \\ \quad B_3B_1)]+p^4[J(B_1B_2+B_2B_3+B_3B_1)+ \\ \quad (f+g)(B_1B_2B_3)]+p^5(JB_1B_2B_3) \end{array}\right\}} \quad (1)$$

The denominator of this expression becomes the characteristic equation for the system. This is a fifth order equation which only can be solved numerically, and it illustrates the intricate interdependence of parameters which result from this approach. Since it is to serve only as an illustration and not for calculation, the detailed derivation is not given.

3. Substitute $p = j\omega$. This results in the equation

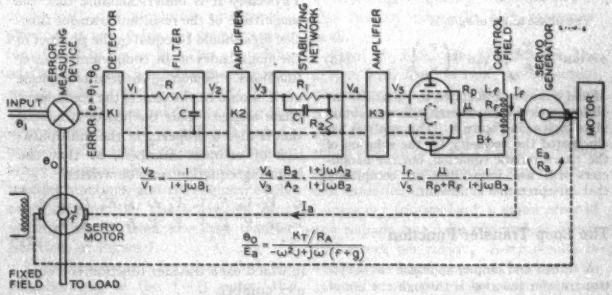

Figure 6. Torque amplifier

θ_o, θ_i = output and input positions in radians

$e = \theta_i - \theta_o$ = error or deviation in radians

V_1, V_2, V_3, V_4, V_5 = direct voltages as shown in figure

$K_1 = \frac{V_1}{e}$, $K_2 = \frac{V_3}{V_2}$, $K_3 = \frac{V_5}{V_4}$ amplification or attenuation ratios

R, C = filter element values

$B_1 = RC$ = filter time constant

R_1, R_2, C_1 = stabilizing network element values

$A_3 = R_1C_1$ = stabilizing network time constant

$B_3 = A_3 \frac{R_2}{R_1+R_2}$ = stabilizing network delay time constant

R_p, μ = output tube plate resistance and amplification factor

L_f, R_f, ϕ_f = servo generator control field inductance, resistance, and flux

$B_2 = \frac{L_f}{(R_p+R_f)}$ = servo generator control field time constant

E_a, I_a = armature circuit generated voltage and current

$T = K_T I_a$ = servomotor torque

J = servomotor plus load inertia

f = servomotor plus load viscous friction

g = effective viscous drag caused by motor back electromotive force

$$\frac{\theta_o}{\theta_i} = \frac{K(1+j\omega A_2)}{\left\{\begin{array}{l} K-\omega^2[J+(f+g)(B_1+B_2+B_3)]+\omega^4[J(B_1B_2+B_2B_3+B_3B_1)+(f+g)(B_1B_2B_3)] \end{array}\right\} + j\omega\left\{\begin{array}{l} (KA_2+f+g)-\omega^2[J(B_1+B_2+B_3)+(f+g)(B_1B_2+B_2B_3+B_3B_1)]+\omega^4 JB_1B_2B_3 \end{array}\right\}} \quad (2)$$

This expression is known as the system response transfer function, and from it the magnitude and phase angle may be determined by the usual manipulations with complex numbers. Thus

$$\frac{\theta_o}{\theta_i} = \frac{R_N+jX_N}{R_D+jX_D} \quad (3)$$

where the R's and X's are all real functions of the angular frequency $\omega = 2\pi f$.

The magnitude of θ_o/θ_i is

$$M = \frac{\sqrt{R_N^2+X_N^2}}{\sqrt{R_D^2+X_D^2}} \quad (4a)$$

The phase angle of θ_o/θ_i is

$$\phi = \tan^{-1}\left(\frac{X_N}{R_N}\right) - \tan^{-1}\left(\frac{X_D}{R_D}\right) \quad (4b)$$

M and ϕ may be calculated by equations 4a–4b for particular parameter values to obtain plots such as in Figure 4. This analysis has eliminated the necessity for the solution of the characteristic equation, but the parameters still are intermixed so completely that interpretation is difficult.

The Loop Transfer Function

A second and simpler approach to the system transfer function is through the use of an auxiliary transfer function which leaves most of the system parameters independent. The type of automatic control under discussion is based upon the use of an error signal which is the difference between the input and output motions,

$$\epsilon = \theta_i - \theta_o = \text{error} \quad (5)$$

This expression yields

$$\frac{\theta_o}{\theta_i} = \frac{\left(\frac{\theta_o}{\epsilon}\right)}{1+\left(\frac{\theta_o}{\epsilon}\right)} \quad (6)$$

Equation 6 is of basic importance, since it states that the complex system transfer function may be expressed in terms of an auxiliary complex transfer function θ_o/ϵ, which may be called the loop transfer function. It will be shown that the loop transfer function is simpler to derive and interpret than the system function, and a geometrical evaluation of equation 6 can be used. The term "loop transfer function" is borrowed from feed-back amplifier terminology,[3] and the similarity of θ_o/ϵ to the often quoted $\mu\beta$ characteristic is apparent.

Reference to Figure 6 indicates that between the output θ_o and the error ϵ there is a series of separate component circuits each with its own transfer function. Physically it is understandable that the magnitude of the resultant transfer function θ_o/ϵ should be equal to the product of the magnitudes of the component transfer functions. Similarly, the resultant phase angle should be the sum of the component phase angles. This method of combination is also a property of the multiplication of complex numbers, so that the following equation may be written:

$$\frac{\theta_o}{\epsilon} = \frac{V_1}{\epsilon}\cdot\frac{V_2}{V_1}\cdot\frac{V_3}{V_2}\cdot\frac{V_4}{V_3}\cdot\frac{V_5}{V_4}\cdot\frac{I_f}{V_5}\cdot\frac{\phi_f}{I_f}\cdot\frac{E_a}{\phi_f}\cdot\frac{I_a}{E_a}\cdot\frac{T}{I_a}\cdot\frac{\theta_o}{T} \quad (7)$$

in which each transfer function is a complex number.

The next step is to calculate all the individual transfer functions for substitution in equation 7. This step requires only simple electrical circuit theory. For the filter,

$$\frac{V_1}{\epsilon}\cdot\frac{V_2}{V_1} = K_1\cdot\frac{1}{1+j\omega RC} = K_1\cdot\frac{1}{1+j\omega B_1} \quad (8)$$

For the stabilizing network,

$$\frac{V_2}{V_3}\cdot\frac{V_3}{V_2} = K_2\frac{R_2}{R_1+R_2}\times\frac{1+j\omega R_1C_1}{1+j\omega R_1C_1\cdot\frac{R_2}{R_1+R_2}} = K_2\frac{B_2}{A_2}\cdot\frac{1+j\omega A_2}{1+j\omega B_2} \quad (9)$$

For the generator field current,

$$\frac{V_3}{V_4}\cdot\frac{I_f}{V_3} = K_3\cdot\frac{\mu}{R_g+R_f+j\omega L_f} = K_3\cdot\frac{\mu}{R_g+R_f}\cdot\frac{1}{1+j\omega\frac{L_f}{R_g+R_f}} = \frac{K_3\mu}{R_g+R_f}\cdot\frac{1}{1+j\omega B_3} \quad (10)$$

For the generated voltage,

$$\frac{\phi_f}{I_f}\cdot\frac{E_a}{\phi_f} = K_4 \quad (11)$$

a constant which depends upon the generator design.

The terms of equation 7 between the generated voltage and the output motion cannot be separated into a series of individual transfer functions, since there is an

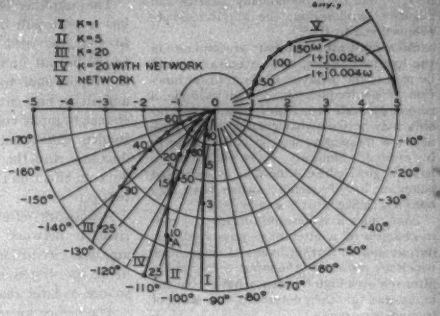

Figure 7. Loop transfer functions

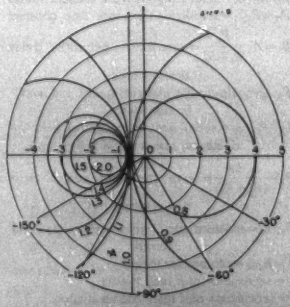

Figure 8. Loci of constant magnitude M on the θ_o/ϵ complex plane

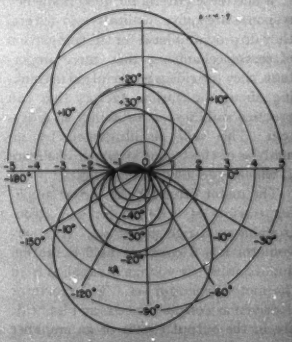

Figure 9. Loci of constant phase ϕ for θ_o/θ_i on the θ_o/ϵ complex plane

interaction between the output motion and the armature current caused by the back electromotive force of the motor. The following three equations specify this interaction:

$$I_a R_a + K_m \frac{d\theta_o}{dt} = E_a$$

$$T = \text{torque} = K_T I_a$$

$$T = J\frac{d^2\theta_o}{dt^2} + f\frac{d\theta_o}{dt}$$

By setting $\frac{d}{dt} = j\omega$ and $\frac{d^2}{dt^2} = -\omega^2$ and combining the three equations:

$$\frac{\theta_o}{E_a} = \frac{\frac{K_T}{R_a}}{-\omega^2 J + j\omega(f+g)} \tag{12}$$

where

$$g = \frac{K_T K_M}{R_a}$$

Finally, for the loop transfer function, the combination of equations 8–12 into equation 7 yields

$$\frac{\theta_o}{e} = K \cdot \frac{1 + j\omega A_2}{\left\{\frac{(1+j\omega B_1)\cdot(1+j\omega B_3)\times}{(1+j\omega B_2)\cdot(-\omega^2 J + j\omega(f+g))}\right\}} \tag{13}$$

where the A's and B's all have the dimensions of time, and the K lumps together all of the gain constants in the loop

$$K = K_1 K_2 \frac{B_1}{A_1} \cdot \frac{K_3 \mu}{R_g + R_f} \cdot K_4 \cdot \frac{K_T}{R_a}$$

Relation Between the Loop and System Transfer Functions

When equation 13 is introduced into equation 6, the system transfer function of equation 2 results. For the graphical interpretation of the relationship 6 between the loop and system transfer functions, it is desirable to plot the loop transfer function in a different manner, on polar co-ordinates. At any one frequency the transfer function has a magnitude and an angle which entirely specify a point on polar co-ordinates. As the frequency varies, the point will move and the resultant locus of points is the plot of the transfer function. Several such loci are shown in Figure 7 with the frequencies shown as numbers along each curve.

On the polar co-ordinate system on which these loop transfer functions are plotted, there must be a locus of points which all result in the same magnitude of system transfer function. These loci are the circles shown in Figure 8 for several different magnitudes. If any frequency point of θ_o/e falls on one of these circles, then the magnitude of the system transfer is determined by the value of M for that curve. Similarly, there are a series of equal phase angle curves ϕ as shown in Figure 9.

The fact that these loci are circles is based upon the representation of θ_o/e as a vector from the origin and $1+(\theta_o/e)$ as a vector to the same point from -1. Then $M = |\theta_o/\theta_i|$, according to equation 6, is the ratio of these two distances, and by a geometrical theorem the loci of constant M are circles of radii $M(1-M^2)^{-1}$ at centers $M^2(1-M^2)^{-1}$. Similarly, the angle ϕ is the difference between the angles of the two vectors, and the loci of constant ϕ are circles of radii $\frac{1}{2}|\text{cosec } \phi|$ at centers $-\frac{1}{2} + j\frac{1}{2}\cot\phi$.

The similarly numbered curves of Figure 7 and those of Figures 4 and 5 correspond to the same system. As an example of this method of calculation, consider the point A at $\omega = 10$ for the loop transfer function II in Figure 7. This point falls on Figures 8 and 9 as shown and corresponds to $M = 1.08$ and $\phi = -17°$. These values then appear on Figure 4 for the same frequency. With sufficient experience with this sort of calculation, it is no longer necessary always to plot the system transfer functions, and the engineer easily can interpret the characteristics of a system directly from the loop transfer functions of Figure 7.

If the loop transfer function falls in the neighborhood of the (-1) point, the resonance of the system becomes very high. Loci near the negative imaginary axis will not have resonance peaks. Also, for all large values of θ_o/e, the magnitude of θ_o/θ_i, will be near unity and the phase angle will be near zero.

The Torque Amplifier Loop Transfer Function

To obtain an understanding of the effect of each component network on a system, it is often desirable to study first a system with only the most important components and then gradually add the less important components. For the torque amplifier system of Figure 6, all the delays and the stabilizing network may be neglected at first, and the simplified loop transfer function

$$\frac{\theta_o}{e} = \frac{K}{-\omega^2 J + j\omega(f+g)} \tag{13}$$

may be studied.

Typical parameter values for a 0.1 horsepower system are

$J = 0.005$-inch-ounces torque for one radian per second² acceleration of the motor.

$(f+g) = 0.125$-inch-ounces torque for one radian per second velocity of the motor.

The value of K is determined by the amplification of the system. Experimentally, if the motor shaft is displaced one radian from zero error, the torque required to accomplish this is numerically equal to K. Curves I, II, and III are drawn for $K = 1$, 5, and 20 inch ounces per radian respectively.

Since K is merely an amplification factor, the loop transfer functions I, II, and III of Figure 7 only are expanded or contracted versions of each other. For $K = 1$, no resonance peak occurs, since the locus does not go near the point -1, but on the other hand the response drops off at a very low frequency. $K = 5$ produces a system with a wider frequency response, but a resonance of 1.38 occurs at $\omega = 25$ radians per second. $K = 20$ has a very wide frequency response, but it also has an extremely high resonance peak.

From the standpoint of resonance, the system with $K = 1$ is best, but its actual performance is poor, since the low frequency response results in a very sluggish system. Moreover, since it requires so much error to produce a torque, any load on the motor will produce a large error. For example, in order to drive a 10-inch-ounces dry friction load, a motor error of ten radians would be required at $K = 1$-inch-ounce per radian. $K = 5$ results in faster and tighter response, but even this is usually not enough for a high performance system. $K = 20$ is much more desirable from every standpoint except that of the high resonance peak.

The design problem usually resolves into the necessity for providing some adequate means for reducing the resonance peak of the system with $K = 20$. The network shown between V_4 and V_3 of Figure 6 is a common one used for this purpose. Its transfer function is

$$\frac{R_2 \cdot (1 + j\omega R_1 C_1)}{(R_1 + R_2)\left(1 + j\omega R_1 C_1 \cdot \frac{R_2}{R_1 + R_2}\right)} = \frac{B_3}{A_3} \cdot \frac{1 + j\omega A_3}{1 + j\omega B_3}$$

and its polar plot is shown in Figure 7 for $R_2/(R_1+R_2) = 0.2$, and $R_1C_1 = 0.02$ second with K adjusted by changing other factors to take care of the attenuation of this circuit at $\omega = 0$ which is 0.2

When this network is inserted in the system, the two complex transfer functions of the unstabilized system and the stabilizing network are multiplied together. Thus, at each frequency the two magnitudes are multiplied and the two phase angles are added so that the network shifts the loop transfer function away from the high resonance region near the -1 point. For the above values and $K = 20$, the resulting loop transfer func-

tion is shown as IV in Figure 7, and the system transfer function is shown as IV in Figure 4.

The introduction of the stabilizing network has reduced the resonant peak to 1.14 at 50 radians per second and also has broadened the frequency response and reduced the phase lag.

An interesting question which illustrates the power of this method is the determination of the proper value for the time constant R_1C_1. The form of the locus which is a circle is independent of R_1C_1, but the position of each frequency point is determined by R_1C_1. For example, if a low time constant of say only 0.002 second had been chosen, the stabilizing network would not be able to introduce an appreciable positive phase angle until the very high frequency region after the loop transfer function already had passed through the highly resonant region. Conversely, if R_1C_1 is too large, say 0.2 second, the large positive phase angles would occur at very low frequencies and the phase would have returned to near zero at the frequencies for which the loop transfer function passes near the point -1. This relationship is shown in Figure 10 by an exaggerated sketch.

The Effect of Delays

With the addition and proper design of the stabilizing network, the torque amplifier has been given quite satisfactory characteristics, but certain delays which initially were assumed to be of secondary importance still are to be investigated. The transfer function for a single delay has been given in equation 10, and it is well known that its locus is a circle with negative phase angles, as shown by curve E of Figure 11. Since such a delay adds a negative phase angle into the loop transfer function it will shift the locus toward the (-1) point and cause an increase in the resonance peak. A delay of this sort is to be considered important or not depending upon whether or not it introduces an appreciable phase shift at the frequencies near the resonant point.

Figure 11, curve A, shows the locus of the stabilized system without delays. Curve B shows the same locus as it is shifted by a 0.004-second delay which might occur with a pentode tube driving the field circuit. In this case the shift increases the resonance to 1.5 from its previous value of 1.14. Curve C shows the effect of a single 0.02-second delay as might occur with a triode driving tube. This delay is quite appreciable and the resonance has risen to almost four.

To illustrate another feature, curve F is the locus of the transfer function for two 0.01-second delays and curve D shows their effect on the system. These two delays might occur in the filter network and in the field circuit, respectively. They have the transfer function $(1+j.01\omega)^{-2}$ and are shown to have a greater effect than that of a single 0.02-second delay.

Curve D of Figure 11 represents a system that is worse than just resonant; it is unstable, and oscillations increase in amplitude with time, rather than die out. Any locus for which the vector from the (-1) point to the locus rotates through a resultant negative angle as ω goes from zero to infinity will be unstable. Thus, curve C could represent also an unstable system if the gain were increased until the locus circled the (-1) point. For a fully rigorous statement and proof of this stability criterion, usually called the Nyquist criterion, reference should be made to the writings of Nyquist,[5] Bode,[7] and MacColl.[8]

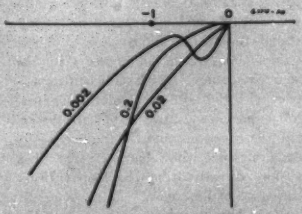

Figure 10. Effect of the stabilizing network time constant on θ_o/θ

In the event that these delays are appreciable, it is necessary to reduce the loop gain or add other suitable phase correcting networks, but since this is only an illustrative example, the design will not be completed here.

Inverse Transfer Functions

Equation 6 may be placed in a form which still further simplifies the calculating procedure in many cases. The reciprocal of equation 6 is

$$\frac{\theta_i}{\theta_o}=\frac{e}{\theta_o}+1 \qquad (14)$$

In this equation θ_i/θ_o and e/θ_o represent an input-to-output ratio rather than an output-to-input ratio and therefore are called the inverse system transfer function and the inverse loop transfer function, respectively. The graphical solution of equation 6 is particularly simple since, if e/θ_o is plotted on the complex plane as before, the same curve may be used for θ_i/θ_o with a new origin at the (-1) point. Loci of constant magnitude and constant phase for θ_i/θ_o are the concentric circles and intersecting lines of the polar co-ordinate system at the (-1) point. Thus $M^{-1}=|\theta_i/\theta_o|$ is the distance from the (-1) point to the locus, and $(-\phi)$ is the angle of the vector from the (-1) point to the locus.

The Calculus of Transfer Functions

When several components or complete systems are placed in cascade, their transfer functions combine as

$$Me^{j\phi}=M_1e^{j\phi_1}M_2e^{j\phi_2}=M_1M_2e^{j(\phi_1+\phi_2)} \qquad (15)$$

This relation was used in equation 7.

Similarly the inverse transfer functions which have the reciprocal magnitude and the negative phase angle of the transfer functions combine as

$$M^{-1}e^{j(-\phi)}=M_1^{-1}M_2^{-1}e^{j(-\phi_1-\phi_2)} \qquad (16)$$

When one component feeds back from the output of another component as shown in Figure 12, the resultant transfer function is

$$Me^{j\phi}=\frac{M_1e^{j\phi_1}}{1+M_1M_2e^{j(\phi_1+\phi_2)}} \qquad (17)$$

while the inverse transfer functions combine as,

$$M^{-1}e^{j(-\phi)}=M_1^{-1}e^{j(-\phi_1)}+M_2e^{j\phi_2} \qquad (18)$$

Since this is only a vector addition, its graphical construction is very simple and provides one of the advantages of the inverse transfer function approach.[6] This is particularly so in the study of regulators and process controls. Another advantage is that it places the loci near the origin for the low frequencies which are of interest.

Regulator Principles

For the torque amplifier example, only its response to an input motion has been considered, and it was desirable for the system to have a wide frequency response. If the torque load on the servomotor should vary, however, it would be desirable to have a minimum response to these variations. That is, if torque variations are considered as an input, the output θ_o should be filtered as completely from these variations as is possible. In this sense the torque amplifier is acting as a regulator, and the use of equation 18 with inverse transfer functions becomes advantageous.

If a torque T_L is applied at the load shaft with the armature circuit connected

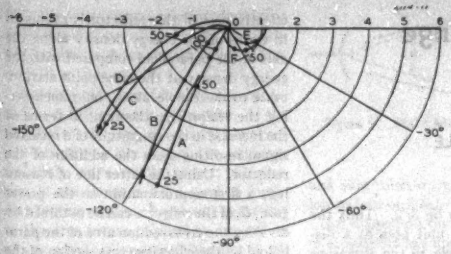

Figure 11. Loop transfer function for stabilized system with delay

A—Basic system with no delays
B—A 0.004-second delay
C—A 0.02-second delay
D—Two 0.01-second delays

but with the amplifier off, the resultant output will be calculated as

$$T_L = Jp^2\theta_o + f p\theta_o - T$$

$$T = K_T I_a = -\frac{K_T K_M}{R_a} p\theta_o = -\xi p\theta_o$$

$$\frac{T_L}{\theta_o} = p^2 J + p(f+\xi) \tag{19}$$

T_L/θ_o is an inverse transfer function and may be identified with $M_1^{-1}e^{-j\phi_1}$ of equation 18.

The return transfer function $M_2 e^{j\phi_2}$, which is the ratio of the torque produced by a motion of the output from the zero error position, is (with $B_1 = B_2 = 0$)

$$M_2 e^{j\phi_2} = K \cdot \frac{1+j\omega A_2}{1+j\omega B_2} \tag{20}$$

Combination of equations 19 and 20 into equation 18 yields

$$\frac{T_L}{\theta_o} = p^2 J + p(f+\xi) + K \cdot \frac{1+j\omega A_2}{1+j\omega B_2} \tag{21}$$

for the system with the amplifier on.

T_L/θ_o of equation 19 represents the inverse transfer function for a disturbing torque with the amplifier off, and as such it is a measure of the self-regulating properties of the load. It is plotted in Figure 13, curve *A*, for the values $J = 0.005$-inch-ounce per radian per second^2 and $(f+\xi) = 0.125$-inch-ounce per radian per second. Thus at $\omega = 10$, T_L/θ_o is only slightly greater than one and only 1-inch-ounce torque is required to move the load with an amplitude of one radian at this frequency.

T_L/θ_o of equation 21 is the same transfer function with the control loop closed. Curve *B* in Figure 13 is the plot for this function, with $K = 20$, $A_2 = 0.02$, and $B_2 = 0.004$. T_L/θ_o is greater than 20 at all frequencies for this system, and this is a measure of how well the torque amplifier is regulated against load changes.

The equivalent condition to a high resonance peak would occur if the locus came relatively close to the origin for certain frequencies. Then disturbances at these frequencies would be regulated less well than disturbances at other frequencies.

Phase and Magnitude Relationships

In the foregoing discussion the phase and magnitude of the transfer function have been treated as more or less independent quantities. Actually since they are derived from the same function of a complex variable, there must be a relation between the two which definitely limits the variety of polar plots which are available in physical systems. Bode[7] has developed several such relations which are useful in feed-back amplifier design and consequently in automatic control design. The dependence of phase upon magnitude for these linear stable systems can be written only in an implicit integral form, but its essence may be stated simply as follows.

In physically realizable stable systems of the kind we are discussing, there is a tendency for the phase angle of a transfer function to depend upon the rate of increase or decrease of the magnitude of the function with frequency. If the magnitude decreases as $1/\omega^2$ over a region of frequency, then the phase will tend toward an angle of $-k\pi/2$ radians. The simple delay $(1+jB\omega)^{-1}$ illustrates this, since at low frequencies the magnitude is slowly varying and the phase is near 0 degrees, while at high frequencies the magnitude decreases as $1/\omega$ and the phase approaches -90 degrees. The transition between two rates of change of magnitude results in a smooth variation in phase between the two values. All the transfer functions plotted illustrate this relation ship.

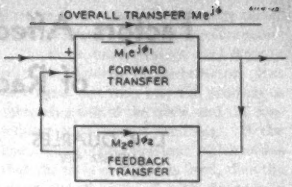

Figure 12 (right). Feedback over a component or system

The important feature to note is that if the loop transfer function magnitude decreases as $1/\omega^2$ or faster for a region near unity, the phase angle will be near $-180°$ or more and the system will be highly resonant. A good loop transfer function should not decrease in magnitude any faster than, say, $1/\omega^{1.5}$ until the magnitude is below about 1. Then the resonance peak will be no greater than 1.3. The stabilizing network discussed in the foregoing is useful, since it has a rising gain characteristic over a region near unity for which the loop magnitude is decreasing too fast. MacColl[8] has demonstrated this approach in detail.

Experimental Techniques

Experimentally many methods for testing a whole system for frequency response or for obtaining the transfer function of individual components will suggest themselves. A sinusoidal disturbance is placed

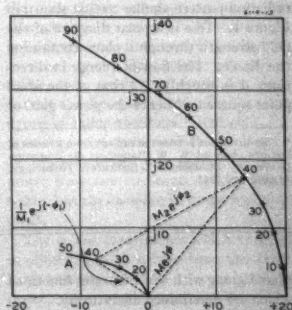

Figure 13. The open and closed loop inverse transfer functions for a disturbing torque

at the input of the component or system, and the relative phase and magnitude of the output is measured. One important advantage of this type of analysis is that the transfer function for some critical component which is difficult to analyze may be determined experimentally and

Factors Affecting the Range of Radar Sets

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IT is now well known that most of the radar sets used in the past war function by transmitting a pulse and measuring the time necessary for the signal to reach the target and the echo to return. Of particular interest is the problem of finding how much power must be transmitted so that the echo will be of sufficient strength to be detected satisfactorily by the radar receiver. When dealing with microwave equipment and the consequent line-of-sight transmission paths, the problem can be solved by geometric means.

Consider a point source which is radiating energy uniformly in all directions.* The rate at which energy passes through unit area at a distance r from the source is $P_t/4\pi r^2$ where P_t is the power output of the transmitter. This must be true because the area of the sphere of radius r, through whose surface all the energy passes, is $4\pi r^2$.

A radar transmitter which radiates equally in all directions is difficult to obtain. However, a very common short wave antenna is the dipole which has a radiation pattern similar to that shown in Figure 1. This is a polar diagram of the field strength through a plane containing the dipole. The flow of energy in directions A is roughly 3/2 that of the ideal point source and hence the power gain of the dipole is said to be 3/2. Thus the energy flow through unit area at a distance r from the dipole, in the directions A, is $3P_t/8\pi r^2$.

Viewed as a receiving system, the so-called effective cross section of a dipole[1] is a function of the wave length, λ, and is approximately equal to $3\lambda^2/8\pi$. This is numerically equal to the cross section of a disk which, if placed normal to the incident radiation, will absorb an equivalent amount of energy. Thus if two similar dipoles are placed a distance r apart, the received power, P_r, in terms of the transmitted power, will be the product of the energy density at the receiving dipole and the dipole cross section,

$$P_r = \frac{3P_t}{8\pi r^2} \times \frac{3\lambda^2}{8\pi} = P_t\left(\frac{3\lambda}{8\pi r}\right)^2 \qquad (1)$$

At microwave frequencies, it is convenient to use a parabolic reflector, with the dipole at its focus to narrow the radiated energy into a beam. Figure 2 is a sketch of this arrangement showing the dipole at the focus of a paraboloid. The effectiveness of this reflector is expressed in terms of the energy density along the axis of the paraboloid compared with the energy density at the same point attributable to the dipole alone, or, remembering the reciprocity theorem, in terms of the increase in the magnitude of a received signal resulting from the addition of the reflector. Using the latter line of reasoning, a first approximation to the power gain, G, of the reflector can be obtained by dividing the cross section area of the paraboloid by the effective cross section of the dipole,

$$G = \frac{\frac{\pi D^2}{4}}{\frac{3\lambda^2}{8\pi}} = \frac{2}{3}\left(\frac{\pi D}{\lambda}\right)^2 \qquad (2)$$

where D is the diameter of the paraboloid and λ the operating wave length. The beam width θ between half-power points in terms of reflector size and wave length is given roughly by

$$\theta = \lambda/D \text{ radians} \qquad (3)$$

Referring to equation 1, if paraboloids are used behind each dipole, then the received power is increased by the product of the gains of these reflectors. Assuming paraboloids of equal size, the expression for the received power P_r becomes

$$P_r = P_t\left(\frac{3\lambda}{8\pi r}\right)^2 \times G^2$$

$$P_r = P_t\left(\frac{\pi D^2}{4\lambda}\right)^2 \times \frac{1}{r^4} \qquad (4)$$

As might be expected, this equation shows that the received power is inversely proportional to the square of the separation.

Figure 1. Field pattern of dipole

* This discussion is adapted in part from a series of lectures given by W. W. Hansen at the Radiation Laboratory, Massachusetts Institute of Technology, in 1940 and 1941.

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placed along with other transfer functions which are determined analytically.

In some cases it may be desirable to work with the magnitude of the transfer function alone because of difficulty in making phase measurements. Then the phase-magnitude relationship is useful.

For experimental verification of the methods discussed, it is important that the system remain linear; in particular, the applied disturbances should not be large enough to overload the amplifiers or saturate the motor. In view of this limitation, this analysis yields necessary conditions for good performance but not always sufficient conditions.

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It is the fundamental relation describing point-to-point operation, such as microwave radiotelephone service where a line-of-sight path is involved.

For the radar case, however, it is necessary to find the energy in the echo. If the target is an airplane, the energy scattered is a function of the size of the airplane, materials, wave length, aspect, polarization of the incident wave, and so forth. An effective cross section A_t can be defined as the area intercepting that amount of power which, if scattered equally in all directions, will give an echo equal to that from the target.

With this assumption, the energy density at a distance r from the target is

$$P_s = P_i \times \frac{A_t}{4\pi r^2} \tag{5}$$

where P_i is the incident energy density and P_s the density of the scattered energy at a distance r from the target.

In a microwave set the same antenna system is used for transmitting and receiving; hence the received energy is the product of equations 4 and 5, since equation 4 represents the energy which would be received if it were reflected without loss of any sort and equation 5 is the loss factor of the target.

$$P_r = P_t \left(\frac{\pi D^2}{4\lambda}\right)^2 \times \frac{A_t}{4\pi} \times \frac{1}{r^4} \tag{6}$$

Will this energy be sufficient to operate the receiver? While it is possible to get almost infinite gain in a receiver, the sensitivity, that is, the smallest signal that the receiver can utilize, is determined by the noise in the receiver input.

The theoretical lower limit of this noise level is fixed by the thermal-agitation-noise (Johnson noise) in the resistive component of the input.[2,3] This thermal-agitation-noise voltage is $\sqrt{4kTBR}$ volts. Remembering that the maximum power which can be drawn from a generator of electromotive force E and internal resistance R is $E^2/4R$, the maximum noise power available to the receiver is kTB watts. Here k is Boltzman's constant, 1.37×10^{-23} Joule per degree absolute, T about 290 degrees absolute; and B the effective noise band width of the receiver in cycles per second, which is roughly equal to the band width of the receiver between half-power points. For satisfactory pulse reception, the band width should be inversely proportional to the length of the pulse. For a one-microsecond pulse, this is 10^6 cycles. The ratio of the equivalent noise level at the receiver input to the thermal-agitation-noise is defined as the "noise figure," symbol F,

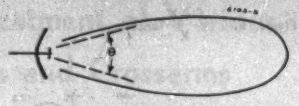


Figure 2. Field with parabolic reflector

and in a microwave receiver may be as low as four or five.

An expression for the maximum range of a radar set can now be written. If it is assumed that a received signal-to-noise ratio of one is acceptable, then the value of the equivalent noise level can be substituted for P_r in equation 6 giving

$$kTBF = P_t \left(\frac{\pi D^2}{4\lambda}\right)^2 \times \frac{A_t}{4\pi} \times \frac{1}{r^4} \tag{7}$$

Solving this for the range r gives the relation

$$r = \sqrt[4]{P_t \left(\frac{\pi D^2}{4\lambda}\right)^2 \times \frac{A_t}{4\pi} \times \frac{1}{kTBF}} \tag{8}$$

To illustrate by a numerical problem, the following is representative of a microwave search radar:

P_t, peak transmitted power, = 100 kw
λ, wave length, = 10 centimeters
Beam width = 3 degrees, or,
D, diameter of reflector, = 190 centimeters
A_t, effective cross section area of a medium bomber, = 2×10^5 square centimeters
B, band width, = 10^6 cycles per second. (This permits a 1-microsecond pulse)
F, noise figure, = 10

The maximum range is then roughly 150 land miles. The airplane could be tracked this far (in theory) if it flew at sufficient altitude to permit a line-of-sight path between it and the radar antenna.

Several interesting conclusions can be drawn from equation 8. The effective range varies at the fourth root of the transmitted power, that is, to double the range it is necessary to increase the peak power by a factor of 16. The range also varies as the fourth root of the effective cross section area of the target. For this reason a large bomber cannot be tracked to a much greater distance than a small fighter. Again, the range appears to be inversely proportional to the square root of the wave length, but this is not the whole story. As shown in equation 3, the beam width is directly proportional to the wave length, and if one endeavors to increase the range by decreasing the wave length with the consequent decrease in beam width, the beam speedily becomes too narrow for successful searching. In other words, it is possible for the beam to pass completely over the target between pulses. Actually it is desirable for at least three or four pulses to strike the target while the beam is sweeping over that point.

The range also appears to vary directly with the diameter of the reflector. But here again one runs into the problem of decreasing size of the beam and the consequent unsuccessful scanning. If the beam width is held constant, which means that the ratio of D to λ is fixed, then the range actually falls off with decrease in wave length, because the size of the reflector must be reduced in proportion to the reduction in λ. It should be added here that a paraboloid, such as was assumed in the foregoing numerical example, is not very practical for a long range search set because the beam is too narrow in the vertical direction. One way to overcome this difficulty is to use a truncated paraboloid which has a considerably wider beam in elevation than in azimuth. The gain, of course, of such a reflector is less than the complete paraboloid.

The range is also proportional to the fourth root of the peak power of a pulse. But increasing the peak power by shortening the pulse to keep the same average power also requires that the band width be increased; hence the noise level of the receiver will increase in proportion. If the peak power is increased without shortening the pulse, which means that the average power is increased, then, of course, the range also will increase, but slowly.

Finally, it is seen that the range is inversely proportional to the fourth root of the noise figure. In fact, as far as this characteristic is concerned, decreasing the noise figure is as effective as increasing the average power. This explains why such a tremendous amount of work has been done in the direction of reducing the noise figure of radar receivers. Reducing the noise figure by three decibels may not be as sensational as increasing the peak power from one megawatt to two megawatts, but the increase in range is just as great.

The recent experiments which resulted in obtaining radar echoes from the moon have been described in a recent publication.[4] After making certain corrections for the increase in gain of the radar antenna caused by reflections from the ground and so forth, it was found that the strength of the received echo agreed closely with the value predicted by calculation. A long-wave radar set was used (110-megacycle frequency and a pulse length, of 0.02 second or more). This long pulse allowed the over-all receiver band width to be reduced to 50 cycles per second with a consequent reduction in the thermal-agitation noise. A peak trans-

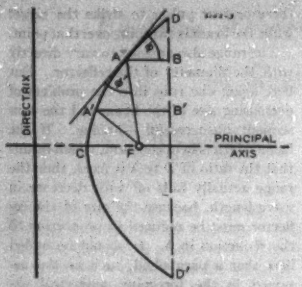
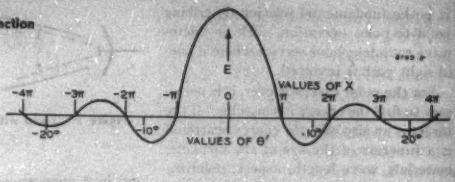


Figure 3. Parabola

Figure 5. $\frac{\text{Sin } X}{X}$ function



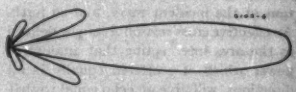


Figure 6. Typical antenna pattern showing side lobes

mitted power of three kw gave a very adequate signal.

Earlier in this paper reference was made to a simple relation for the gain of a parabolic reflector (equation 2), and an idealized field pattern with only one lobe was shown in Figure 2. The true picture is somewhat more complicated. Because the diameter, or aperture, of the reflector is at the most a few dozen wave lengths, the field distribution is the result of diffraction of the radiation at the aperture. Hence the gain depends on other factors beside the size of the reflector and the wave length, and the field shows side lobes in addition to the main lobe.

A complete mathematical discussion of the action of the dipole and parabolic reflector is long and rather involved. However, a qualitative discussion will give a reasonably clear picture.

By definition a parabola is the locus of a point whose distance from a fixed point, the focus, is equal to its distance from a fixed line, the directrix (Figure 3). The parabola also has the property that the angle which any focal radius, such as FA, makes with a tangent to the parabola at the point of intersection is equal to the angle the tangent makes with a line through this point of intersection and parallel to the principal axis. These angles are shown as ϕ and ϕ' on the figure.

A geometric construction shows at once that the distance from the focus to any point on the parabola plus the distance from that point to a line parallel to the directrix but situated on the other side of the vertex is a constant. Referring again to Figure 3, this means that $FA+AB=FA'+AB'$, and so forth.

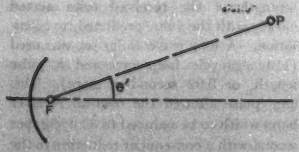


Figure 4. Location of point P

If a source of radiation is placed at F and DCD' is a parabolic reflector, all the waves reflected from it will arrive at DD' in time phase. Therefore we can consider DD' (actually the disk equal to the aperture of the parabola) as a constant phase surface radiating to the right. Next this constant phase surface can be divided into elemental areas and the contribution of all these areas to the field at the point under consideration summed. In general, the distribution of the field intensity will have the form

$$E = (\text{constant})(1+\cos\theta')\frac{\sin X}{X} \qquad (9)$$

where

$$X = \frac{\pi D}{\lambda}\sin\theta'$$

D = diameter of paraboloid DD'

θ' = angle between principal axis and line from focus to point under consideration (Figure 4)

Figure 5 is a plot of this function for D/λ roughly equal to ten, and Figure 6 is a polar plot of the field for a somewhat smaller reflector. The pattern of field intensity can be altered drastically by changing the focal length of the parabola, by distorting the reflector, and by varying the field intensity distribution across the aperture. The presence of direct forward radiation from the dipole feed also modifies the pattern. If the dipole is placed an odd number of quarter-wave lengths from the vertex of the parabolic reflector, then the forward radiation will reinforce the reflected wave (remembering that a wave is reflected with a 180-degree reversal in phase), and if placed an even number of quarter-wave lengths will tend to cancel it.

A typical design of a parabolic reflector calls for a ratio of focal length to diameter equal to 0.30 and also specifies that the product of the focal length and the depth shall equal one-fourth the diameter. Under these conditions, with a dipole feed, the gain is roughly that given in equation 2 and the beam width between half-power points $1.2\,\lambda/D$ radians. With a reflector of reasonable size, the side lobes are small enough to be unobjectionable.

The relations just discussed do not take into account any of the phenomena associated with refraction or reflection from external surfaces, or the fact that very short waves are absorbed by fog and rain.[5] For wave lengths much less than one inch, the latter problem is serious. Reflection can be both an aid and a hindrance. Properly situated ground radar search sets are subject to increases in received signal strength of as much as 12 decibels caused by ground reflections. On the other hand, when the target and the radar set are near the surface of the earth, it is entirely possible for the difference in path lengths of a direct and reflected echo (that is, the ray reflected from the surface of the ocean) to be some odd multiple of a half-wave length, and in this case the resultant echo field will be very nearly zero. This phenomenon has been encountered when searching for ships with shore-based radar sets.

Further work is being done on the measurement of the absorption by the atmosphere of wave lengths less than one inch. As might be expected, there are strong absorption bands due to oxygen, water vapor, and so forth. The results will have considerable bearing on future selection of wave lengths.

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The Preservative Treatment of Various Species for Poles and Crossarms

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THE heavy drain that the war has imposed on the forests of America, the backlog of pole requirements that has been built up over the war period, and the present labor shortage have made it impracticable to obtain a sufficient number of poles of the species formerly used.

Up to the present time, southern yellow pine and western red cedar have been the species most extensively used for poles. Coast Douglas fir and northern white cedar also are recognized as good pole woods, but poles of these species have not had the wide distribution nor the extensive use that southern yellow pine and western red cedar poles have had. In addition to the woods mentioned, treated lodgepole pine poles have been used to a limited extent in the Rocky Mountain region.

Cedar poles and in certain localities some of the less durable species have been used in past years without preservative treatment, but the present discussion will be confined to poles that are to be treated. Since the sapwood of all species has low resistance to decay, the economy of preservative treatment is recognized even for cedar poles that normally have a fairly thin sapwood and a naturally durable heartwood.

In order to meet some of the problems resulting from the current pole shortage, specifications have recently been prepared covering pole species to be used by the Rural Electrification Administration. The American Standards Association has prepared specifications designated as "American War Standards Specifications and Dimensions for Wood Poles." The specifications mentioned cover miscellaneous conifers that are to be given a preservative treatment and that heretofore have not been included among the recognized standard pole woods.

The proposed substitute woods have been grouped according to the allowable fiber stress in the following order:

Group I. Fiber stress 5,600 pounds per square inch
(*a*). Atlantic white cedar (*Chamaecyparis thyoides*)
(*b*). Spruce (*Picea*)—all species

Group II. Fiber stress 6,000 pounds per square inch
(*a*). Eastern white pine (*Pinus strobus*)
(*b*). Ponderosa pine (*Pinus ponderosa*)
(*c*). Sugar pine (*Pinus lambertiana*)
(*d*). Western white pine (*Pinus monticola*)

Group III. Fiber stress 6,600 pounds per square inch
(*a*). Jack pine (*Pinus banksiana*)
(*b*). Red (Norway) pine (*Pinus resinosa*)
(*c*). White fir (*Abies concolor*)

Group IV. Fiber stress 7,400 pounds per square inch
(*a*). Douglas fir other than coast type (*Pseudotsuga taxifolia*)
(*b*). Eastern hemlock (*Tsuga canadensis*)
(*c*). Western hemlock (*Tsuga heterophylla*)
(*d*). Eastern larch (Tamarack) (*Larix laricina*)
(*e*). Western larch (*Larix occidentalis*)

The foregoing fiber stresses were obtained from a study made by the Forest Products Laboratory and are based on the American Standards Association recommended stresses for lodgepole pine.

Wood Preservatives for Poles

Creosote

Prior to the war a large proportion of the poles used in the United States were treated with American Wood Preservers Association specification grade one coal tar creosote with a specified distillation residue of not over 20 to 25 per cent above 355 degrees centigrade.

The federal specification covering creosote for pole treatment limits the residue to 25 per cent. Shortages resulting from the war, however, made it difficult to obtain cresote with a low distillation residue, and it became necessary to increase the allowable residue in the federal specification to as much as 35 per cent. This wartime emergency provision has been discontinued. An important reason for specifying low residue cresote oils for pole treatment is to reduce the tendency to bleed.

Before the war a large amount of creosote was imported from Europe and Japan. Because this supply practically has been cut off and because the domestic production probably will not be able to meet the heavy postwar demands, a creosote shortage may exist for some time to come. This situation has forced pole users to consider the use of other preservatives less well known but that offer promising results. In extreme cases it even may be necessary to use treatments that are known to be less economical because of the shorter service life obtained. Such treatments may be less economical because the materials lack the preservative properties suitable for conditions under which poles are used or because of inadequate treatment. Nevertheless, there should be few cases where inferior and uneconomical treatment is necessary because of present shortages.

Chlorinated Phenols

During the past ten years, the chlorinated phenols have been receiving considerable attention as possible substitutes for creosote or as materials that can be used in mixtures with creosote.[1,2] Pentachlorophenol is the best known in this group and has been the most extensively used, but tetra-chlorophenol and 2-chlororthophenylphenol, in mixtures with pentachlorophenol, have also been given consideration. Pentachlorophenol has the advantage of a lower water solubility than the other two phenolic compounds. Tests show that these chemicals have a high degree of toxicity, and five per cent solutions (on a weight basis) are apparently suitable when solution absorptions needed to obtain the necessary penetrations are employed. A five per cent solution of penetachlorophenol (on a weight basis) commonly is recommended at present. This is for absorptions similar to those specified for pole treatment with creosote.

Both toxicity and permanence are highly important qualities of a good wood preservative, but only long-time service tests provide a satisfactory measure of permanence, and such tests are needed to determine fully the relative merits of the chlorinated phenols. The limited number of service tests that have been started during the past few years indicate that the chlorinated phenols have a promising future, but little information is available on the performance of these solutions when applied by the pressure process. Data thus far obtained apparently indicate that solutions of the chlorinated phenols made with the heavier petroleum

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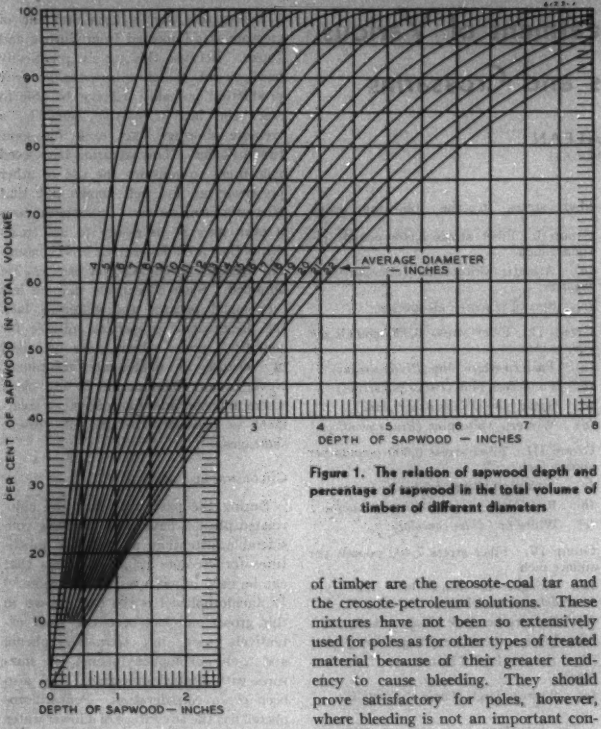

Figure 1. The relation of sapwood depth and percentage of sapwood in the total volume of timbers of different diameters

oils may give better protection than solutions in which the more volatile oils are used. On the other hand the more volatile oils penetrate the wood more readily when the solutions are applied by nonpressure methods. It has been found that some petroleum oils are more suitable than others both as solvents and from the standpoint of freedom from sludging.

The problem of sludging is also of importance in the use of creosote-petroleum mixtures. Experience has shown that petroleum oils with an asphaltic base are much less likely to give trouble than the oils with a paraffin base. Some pole users now are having poles treated with pentachlorophenol mixtures containing varying proportions of coal tar creosote. These mixtures also have an increased tendency to cause sludging unless a suitable petroleum oil is employed.

Creosote Solutions

Blended preservative oils that have been used successfully for various kinds of timber are the creosote-coal tar and the creosote-petroleum solutions. These mixtures have not been so extensively used for poles as for other types of treated material because of their greater tendency to cause bleeding. They should prove satisfactory for poles, however, where bleeding is not an important consideration.

Bleeding

The problem of bleeding is of particular interest when poles are used in urban line construction where the oily surface may cause damage to clothing and result in public complaint. Bleeding is naturally of less importance in rural lines, but in any case it is objectionable to linemen who must climb the poles when the line is installed and when repairs are required. The bleeding problem may be particularly aggravating when the poles have been treated shortly before they are placed in service. While this trouble becomes less acute after the poles have been in service for a time, in some installations bleeding may persist to a variable extent for a considerable period.

It must not be assumed that all poles treated with preservative oils bleed, but it is difficult to predict what poles, if any, will bleed and to what extent they will bleed.

Five factors that appear to have an important bearing on bleeding are

1. Type of preservative oil used.
2. Absorptions obtained.
3. Method of treatment.
4. Species.
5. Temperature conditions to which the wood is exposed.

Heavy absorptions usually cause more bleeding than light absorptions, heartwood will bleed more than sapwood, and species with the more resistant sapwoods will normally bleed more (with the same absorption) than species in which the sapwood is easily penetrated. Bleeding may occur either in summer or winter but is generally most severe in the hot summer months. Straight coal tar creosote usually gives less bleeding trouble than mixtures of coal tar creosote and petroleum, or creosote-coal tar solutions. Likewise, creosote with a high residue above 355 degrees centigrade usually causes more bleeding than low residue creosote oils.

Methods of Treatment

Pressure Treatment

The pressure process is the most effective method of treating timbers of all kinds, since it affords a means of controlling the pressure to any desired amount. By using different initial air pressures, a considerable variation in absorption can be obtained, thereby making it possible to get heavy or fairly light absorptions for a given depth of penetration. The principal objection to pressure treatment is that it requires relatively large and expensive equipment and is therefore not well adapted for the treatment of small quantities of timber nor for treating material that would require long distance transportation to the treating plant.

Nonpressure Treatment

Next to pressure treatment, the hot-and-cold bath method is the most effective. This treatment depends on atmospheric pressure utilized by first heating the wood in a heating medium and then cooling it in the preservative. When the wood is heated, the air contained within its cells is expanded, and part of that in the surface region of the timber is forced out of the lumina or air spaces. In the subsequent cooling bath, a partial vacuum is formed and more or less preservative is forced into the wood cells by atmospheric pressure, depending upon the permeability of the wood and upon the amount of air forced out by

expansion during the heating period. Very little preservative is absorbed during the hot bath, and it is obvious that the pressure forcing preservative into the wood during the cooling period cannot exceed atmospheric pressure. Generally the available pressure will be lower than atmospheric. For this reason the hot-and-cold bath treatment is more suitable for treating round timbers in which only the more easily treated sapwood needs to be penetrated. This method has been extensively used in the butt treatment of western red cedar poles and now is used to some extent in full length treatment of these poles. Lodgepole pine poles also have been butt treated by this method for use in the Rocky Mountain area.

Incising before treatment has been found very helpful when the sapwood is somewhat resistant to penetration, as in the case of cedar. When the sapwood is very resistant to penetration, as in species like the true firs and spruces, it is doubtful that even when the resistant sapwood is incised it will be possible to obtain satisfactory penetration without the use of pressure treatment.

The principal advantages of the hot-and-cold bath treatment over pressure treatment are

1. The cost of the treating equipment is small compared with the cost of pressure treating equipment.
2. Butt treatment or full length treatment can be used as desired.
3. It is more convenient to treat small quantities of timber by this method.
4. It is usually possible to make the treatments near where the timber is cut.

The principal disadvantages are

1. The pressure available for forcing the preservative into the wood is limited compared with the wide range of pressures available when the pressure process is used.
2. Considerably heavier absorptions usually are required for a given penetration than when the wood is treated by pressure methods because an initial air pressure cannot be applied as in the Rueping treatment.
3. This method of treatment is not well adapted for round timbers with unusually resistant sapwood nor for species that have a deep sapwood easily penetrated, since in species having a deep sapwood undesirably heavy retentions may be obtained or there may be incomplete sapwood penetration.
4. Evaporation of the lower boiling constituents of preservative oils used in the hot bath often causes an appreciable loss of preservative.

Absorption Specified for the Pressure Treatment of Poles

Most of the southern yellow pine and Douglas fir poles treated up to the present time have been treated by the empty-cell process with specified minimum net retentions of about eight pounds of creosote per cubic foot. Minimum absorptions specified for lodgepole pine poles have ranged from about four to eight pounds per cubic foot. The lower absorptions specified for the lodgepole pine have been possible partly because of the more shallow sapwood in this species. The sapwood of lodgepole pine commonly ranges from about one half to two inches in thickness compared with two to four inches in southern yellow pine and one to two inches in coast Douglas fir poles. Another reason for the use of lower absorptions in lodgepole pine is that poles of this species have been used mostly in the Rocky Mountain states where decay conditions are usually much less severe than those under which the southern yellow pine and coast Douglas fir poles are used.

Present American Wood Preservers Association specifications for the treatment of southern yellow pine poles permit a minimum net retention of six pounds per cubic foot provided the penetration specified for the 8-pound treatment is met and provided the poles are to be used under conditions that do not favor rapid decay. Various power companies have specified net retentions ranging from 10 to 16 pounds of either creosote or creosote-coal tar solutions in southern yellow pine poles.

The question of obsolescence is usually of more concern to telephone and telegraph companies than to power companies, and it is natural that they do not want to employ preservative treatments that may give a service life well beyond the time their pole lines would become obsolete. On the other hand, it obviously would be unwise and uneconomical to count on obsolescence and later find the service life was too short.

Sufficient service records are not yet available to show the minimum absorptions of different preservatives that can be expected to give satisfactory results for poles of different species when used under various climatic conditions. For this reason it would seem desirable to defer the extensive use of absorptions much lower than those commonly specified until the relative merits of the lower absorptions can be determined from suitable service tests. The following are some of the more important advantages of using absorptions that are known to be adequate as demonstrated by experience:

1. They furnish a better reserve against depletion by leaching and evaporation.
2. They insure better distribution and deeper penetration of the preservative.
3. When the preservative has a variable toxicity, the heavier absorptions serve as a safeguard against deficient toxicity.
4. They reduce the danger of insufficient absorption because of careless treatment.
5. They help protect against the possibility of inadequate treatment of the more resistant timbers in a charge or of those of the larger sizes when the charge contains timbers of different dimensions.
6. They reduce the danger of wide variations between the maximum and minimum penetrations obtained in the same or in different timbers.

The principal disadvantages of heavier absorptions are the somewhat higher initial cost of treatment and the possibility of objectionable bleeding when oily preservatives are used. The higher initial cost of treatment, however, does not necessarily mean that the annual charge will be higher over the period the timber is in service. Within reasonable limits the higher first cost may be much more than offset by the increased service life and consequent reduced cost of renewals.

There are a variety of factors that should be kept in mind in deciding upon the net retention that will prove most economical or most desirable because of other considerations.

The thickness of sapwood also will have a definite bearing on the absorptions that should be specified. Woods with deep sapwood, like that of ponderosa pine, red pine, and the southern pines, naturally have a greater proportion of wood that can be treated than poles of thin sapwood species, like the cedars, western larch, and mountain type Douglas fir. Figure 1 shows the proportion of sapwood in the total volume of poles of different average diameters ranging from 4 to 22 inches. These curves were computed from the relation that if t is the average depth of sapwood and D is the average diameter of the timber, the percentage of the sapwood P, based on the total volume, is given by

$$P = 100\left[\frac{4t(D-t)}{D^2}\right] \qquad (1)$$

If P_t is the percentage of sapwood in the total volume when the average sapwood thickness is t inches, and P_T is the percentage of sapwood in the total volume when the average sapwood thickness is T inches, then

$$\frac{P_t}{P_T} = \frac{t}{T}\left[\frac{D-t}{D-T}\right] \qquad (2)$$

For example, assume $D = 10$ inches, $t = 0.75$ inch, and $T = 3$ inches. Then the ratio

$$\frac{P_t}{P_T} = \frac{0.75}{3}\left[\frac{10-0.75}{10-3}\right] = 0.33$$

In other words, a 10-inch-diameter pole with a sapwood thickness of 0.75 inch would have about 33 per cent as much sapwood as a pole timber of the same diameter with a sapwood thickness of three inches. Equation 1 or Figure 1 shows that the percentage of sapwood in the total volume of a timber 10 inches in diameter with a sapwood thickness of 0.75 inch is about 27.7, while the same diameter timber with an average sapwood thickness of three inches would have about 84 per cent sapwood in the total volume. For the same concentration of preservative, it might be assumed that poles with a sapwood thickness of 0.75 inch would require only 33 per cent as much preservative as when the sapwood is three inches thick. It should be borne in mind, however, that there is a greater opportunity for more rapid loss of preservative from thin sapwood through leaching and evaporation because the preservative is concentrated closer to the surface. In the latter case, somewhat heavier absorptions would help compensate for this difference in depth of penetration.

Equation 2 will be found convenient for comparing the relative proportions of sapwood in a timber of any given diameter when different depths of sapwood are assumed.

Treating Conditions and Pressure Treatment Specifications

In addition to specifying the preservative, the average absorption and penetration required, and the method of seasoning or conditioning the poles for treatment, it is desirable to specify the maximum preservative temperatures and pressures to be used, since these have an important bearing on the success of treatment. Some species will withstand more severe treating conditions than others.

Conditioning

Green southern yellow pine poles commonly are conditioned for treatment by the steaming and vacuum process. Although the average amount of water removed is usually not more than about five to six pounds per cubic foot, the removal of this amount of water and the heating of the wood to a favorable treating temperature as a result of the steaming make this method a very satisfactory means of conditioning southern yellow pine poles. This method, nevertheless, is not well adapted for conditioning other woods commonly treated because either the other woods are injured more easily by the temperatures and heating periods required in steam conditioning or the final moisture content still may be too high for good penetration after the steaming treatment is applied.

Green coast Douglas fir poles are conditioned by the Boulton, or boiling under vacuum, process. In this process, round timbers are usually boiled under vacuum with a specified maximum preservative temperature of 220 degrees Fahrenheit. Since water is evaporated during the boiling period, the wood temperature is usually considerably lower than the temperature of the heating medium. This process also is applied in the conditioning of other species in the green condition and has the advantage that it removes water from green material under mild temperature conditions.

Air seasoning is, of course, the most widely used method of conditioning wood preparatory to treatment.

Treating Temperatures

Both laboratory experiments and subsequent studies made under commercial treating conditions have shown that treating temperatures of 190 degrees to 200 degrees Fahrenheit are much more effective in obtaining good penetrations than lower temperatures. This applies when either preservative oils or water solutions are used. Temperatures a little higher than 200 degrees Fahrenheit often can be used to advantage for some species, such as the southern pines.

Preservative Pressures

Preservative pressures should be kept low enough to prevent objectionable checking and collapse. Some species, as for example southern yellow pine and some of the hardwoods, can withstand treating pressures considerably higher than many other woods. Whenever objectionable checking or collapse occurs as a result of the temperature and pressure conditions employed, the preservative temperature should be maintained in the range of 190 degrees to 200 degrees Fahrenheit, and the treating pressure should be lowered as may be needed to prevent unnecessary checking or collapse.

Specifications

The American Wood Preservers Association for many years has had specifications covering the pressure treatment of southern yellow pine and coast Douglas fir poles, and these specifications have been revised at various times. In recent years this association has prepared specifications for the pressure treatment of western red cedar, lodgepole pine, jack pine, and red pine poles.

Treatment of Species Listed in the Various Groups

The recommendations made in the subsequent discussion are based on experiments made by the Forest Products Laboratory in a study of the treatment of the species named.

Species in Group I. Atlantic white cedar has a sapwood depth about the same as that of western red cedar (about one half to one inch for most timbers) and can be treated under the same conditions as specified for western red cedar (American Wood Preservers Association).

The spruces are resistant to penetration in both the sapwood and heartwood, and it is also difficult to distinguish the sapwood from the heartwood. Sapwood of the freshly cut timbers usually has a high moisture content in the range of 140 to 165 per cent or over. In order to avoid objectionable checking and collapse in the spruce species, it is desirable to limit the preservative pressure to about 150 pounds per square inch when the Rueping process is used and to about 120 to 130 pounds per square inch when the Lowry, or full cell treatment, is applied.[5]

Species in Group II. The sapwood of ponderosa pine usually ranges from about two to three inches in thickness, and the sapwood moisture content of the freshly cut wood is relatively high, averaging about 150 per cent. This is one of the few softwood species that are comparatively easy to treat in both the sapwood and heartwood when air seasoned.

The sapwood of the white pines commonly ranges from about one to two inches and occasionally to three inches in thickness.

In general, the treating conditions specified for the southern pines will be suitable for the pines listed in group II.

Species in Group III. Jack pine has a sapwood that commonly ranges from about $1^1/_2$ to $2^1/_2$ inches in thickness, although poles grown in some regions may have sapwood considerably less than one inch in thickness. Like lodgepole pine, this species is injured more easily by high pressures than some of the other pine species, and the maximum treating pressure should not exceed 150 pounds per square inch and in most cases should be somewhat lower. The treatment of poles of this wood is covered in the American Wood Preservers Association specification for the pressure treatment of jack pine poles.

Red (Norway) pine has a fairly deep sapwood that ranges from about two to four inches in thickness. This species has

a high average moisture content of about 135 per cent in the sapwood when the timber is freshly cut. The treatment of poles of this species is covered in the American Wood Preservers Association specification for the pressure treatment of red pine poles.

The white firs, like the spruces, are very resistant to treatment in both the sapwood and heartwood, and the sapwood is not distinguishable from the heartwood. Treating conditions previously discussed for the spruce species also will apply for the true firs, such as white fir (*Abies concolor*).

Species in Group IV. The sapwood of Douglas fir poles grown in the region between the Pacific Coast and the Cascade Mountains normally has a range in thickness of about $^3/_4$ to $2^1/_4$ inches. In most cases it will average between 1.3 and 1.4 inches. The moisture content of the sapwood in freshly cut timbers usually will average around 115 per cent. The treatment of the coast-type Douglas fir poles is covered in the American Wood Preservers Association specification for the pressure treatment of coast Douglas fir poles.

The mountain-type Douglas fir has a thinner sapwood than the coast type and is usually about one inch or less in thickness. The so-called Inland Empire or intermediate type that grows between the coast and the Rocky Mountain region has a sapwood thickness ranging from about one to two inches.

While the heartwood of the timber that grows in the Rocky Mountain region is far more resistant to treatment than the heartwood of the timber grown in the coast region, the sapwood of the mountain type can be treated satisfactorily by the pressure process. Although the mountain type wood has a lower mechanical strength than the coast wood, the timber grown in the mountain region will withstand a somewhat higher treating pressure without showing a marked increase in checking and collapse. Treating pressures as high as 140 to 150 pounds per square inch generally can be used for the Rocky Mountain wood, while it is usually desirable to use pressures 25 to 30 pounds lower for the coast material.

The sapwood of eastern hemlock is difficult to distinguish from the heartwood and, like the heartwood, is relatively resistant to treatment. The average moisture content of the sapwood of the eastern species is in the neighborhood of 120 per cent in freshly cut wood. Poles of this species should be air seasoned for treatment.

The sapwood of western hemlock is sometimes lighter in color than the heartwood and is usually not much over an inch in thickness. The average moisture content of the sapwood of the western species is considerably higher than that of the eastern species and averages around 170 per cent. Both hemlock species can be treated using pressures up to about 150 to 160 pounds per square inch.

The sapwood of both eastern and western larch is usually less than one inch in thickness; hence the sapwood thickness of these woods is similar to that of the cedars, Rocky Mountain Douglas fir, and western hemlock. The average moisture content of the sapwood of freshly cut western larch is in the neighborhood of 125 per cent.

Treating pressures as high as 175 pounds have been used in treating larch timbers. This species usually can withstand somewhat higher treating pressures than most of the softwoods grown in the western states.

The purpose of the foregoing outline discussing treating conditions and specifications is to point out some of the more important variables that should be considered in the preparation of specifications for pressure treatment. It should be borne in mind that if the best results are to be obtained, the treating conditions should be adjusted to meet the structural variability of the different woods.

Crossarms

The suitability of a given species for crossarms will depend largely on the strength properties and freedom from such defects as cross grain and knots.

Up to the present time, southern yellow pine and coast Douglas fir have been considered the standard woods for crossarm material. The southern pines usually have a larger proportion of sapwood, and since the crossarms of this species are used in large quantities in the South where service conditions are more severe, it is customary to pressure-treat them. The absorptions commonly specified range from around 8 to 12 pounds of creosote per cubic foot.

Coast Douglas fir crossarms generally are used without treatment because they normally have little sapwood and are used more widely in the northern and western states where decay conditions are less severe than in the southern states.

Conditions under which crossarms are used are generally less favorable to decay than where wood is in contact with the soil. For this reason the heavier absorptions used for timbers exposed to the more severe service conditions are not so important for crossarms. The shortage of southern yellow pine and Douglas fir arms that, as in the case of poles, has developed as a result of the war, has made it necessary to consider substitute species.

In the pole species listed under groups I to IV, the conifers that seem most promising for crossarm material include western larch, mountain or intermediate-type Douglas fir, western hemlock, and red pine.

Treatment of Crossarms

Species that have a considerable proportion of sapwood or that do not have good durability in the heartwood should be treated if good service life is to be obtained. Woods of this kind include western hemlock and the various pine species.

Crossarms made from western larch or the Rocky Mountain and intermediate-type Douglas fir would have little sapwood because of the thin sapwood in trees of these species. The heartwood of these woods is similar to the coast-type Douglas fir heartwood from the standpoint of natural durability. When heartwood crossarms are pressure-treated, it is probable that it would be difficult to keep the net retentions much below five to six pounds per cubic foot because of the large amount of surface area in proportion to the volume. Pressure treatment, however, should give deeper penetrations in heartwood material, and when there is a considerable amount of sapwood it should require somewhat lower net retentions than when the open-tank treatment is used.

One of the larger pole using companies has now revised its crossarm specifications to include open-tank-treated red pine, jack pine, lodgepole pine, and the inland or intermediate Douglas fir. Jack pine and lodgepole pine are somewhat lower in strength properties than the other species named, but it is assumed that they will provide suitable crossarms for the lighter service conditions. This company has treated several thousand arms of these woods using a hot bath of coal tar creosote and a cold bath of five per cent pentachlorophenol in an aromatic petroleum oil. These treated arms have been installed in service, and an examination of their condition is to be made at various periods.

Although the use of the pentachlorophenol solutions is still in the experimental stage, it would seem that an open-tank treatment, such as that mentioned, should give good results. The open-tank treatment of crossarms appears to be the most suitable substitute treatment where pres-

Electric Equipment for Cornell Variable Density Wind Tunnel

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Synopsis: Spectacular advances in airplane design during the past decade have created an increasing demand for additional testing facilities with which to obtain those data essential to successful design. To answer partially this demand and to facilitate more basic aerodynamic research on the subject of compressibility effects experienced in high speed flight, several new wind tunnels were constructed during this same period. These tunnels vary widely in size and in requirements for air density and air speed in the tunnel working section. Correspondingly, the horsepower output requirements for their main fan drive motors vary widely. But in all cases close speed regulation at preselected speed values over a wide range is essential to good test results. Most modern tunnels also incorporate suitable electric equipment for the operation of powered models and for the calibration of motors used in these models. This paper describes the Cornell variable density wind tunnel from the viewpoint of electrical engineers and discusses principles governing the selection of electric equipment for wind tunnels.

THE WIND TUNNEL with details as shown by Figure 1 is the variable density high speed tunnel recently constructed by the Curtiss-Wright Corporation Research Laboratory (now Cornell Aeronautical Laboratory), Buffalo, N. Y. This project was initiated by Doctor Norton B. Moore, then of the Curtiss-Wright Corporation, and construction was started under his direction in 1942. The basic design of the tunnel was prepared by members of the staff of the California Institute of Technology under the supervision of Doctor Clark B. Millikan. This group also acted as consultants during construction of the new facility. The design was financed jointly by the Curtiss-Wright Corporation and by a group of four Southern California aircraft companies which finances and owns a basically similar facility, known as the cooperative wind tunnel, in Pasadena, Calif.

The tunnel consists of a reinforced steel duct of circular cross section, housed in a brick-faced frame building, which adjoins a laboratory and power plant building. The principal dimensions of the duct, which is built of steel plate approximately seven-eighth inch thickness, are shown in Figure 2. The duct forms a closed circuit through which air is circulated by the fan system indicated as *A* in Figure 1. With the outlet door of the tunnel closed the static pressure of the air in the tunnel may be varied between one-fourth atmosphere and four atmospheres, and then the air may be caused to circulate in this condition. Vanes built into each corner to guide the air flow are shown in Figure 2. Cooling of the air is accomplished by a bank of finned coil radiators mounted on the downstream side of the turning vanes in one corner of the tunnel. This is shown at *B* in Figure 1. Cooling water is pumped through these radiator coils and the heat is transferred to the atmosphere by means of the cooling tower shown at *C* in Figure 1. This cooling system is of adequate capacity to remove heat corresponding to the maximum continuous power input to the fan system, while limiting the air temperature inside the tunnel to 125 degrees Fahrenheit.

The airplane model shown as *D* in Figure 1 is supported in the "test section" of the tunnel within a sphere, which can be isolated from the rest of the tunnel duct by means of lock gates. This arrangement, unique to this tunnel and the similar one at the California Institute of Technology, Pasadena, allows pressure to be maintained in 90 per cent of the total tunnel volume, while the sphere is isolated decompressed, and the model serviced or changed. Considerable effort was made in the design to speed up this process, thus reducing to a minimum the time during which the tunnel is out of service.

In Figure 2, in the plan view of which the air flow is counterclockwise, the contraction leading into the "working section" and the diffuser downstream of the working section are shown. The inside diameter of the duct at the beginning of the contraction is 31 feet 6 inches, the cross-sectional dimensions of the working or experimental area are 12 feet wide by 8½ feet high, and finally the inside diameter of the duct at the end of the diffusion area (ahead of the first corner downstream of the working section) is 17 feet 9 inches. The airplane model is mounted on supports which, when the tunnel is operating, are integral with a basic metrical (force measuring) system, to which the forces and moments produced on the model by the air stream thus are transmitted. These forces and moments are transmitted hydraulically to a "control" room for indication and recording. For servicing or changing of a model, a transfer cart, the top of which forms the floor of the working section, is raised and carries with it the model supporting struts. Raising of the transfer cart floor disengages the support system from the metrical system and provides clearance for the transfer cart to be motored out of the tunnel on steel transfer rails. Interchangeable transfer carts make it possible to set up completely and "instrument" one model in the model preparation room while a second model is in the tunnel under test.

The fan system, mentioned previously, is driven through a 30-foot hollow steel shaft by a 10,250-horsepower continuous rated 2-unit motor set. Speed adjustment of this drive over a range from 0 to 570 rpm, with close regulation at preset values between 50 and 570 rpm, is arranged for remote operation from the control room near the tunnel door. Power supply for the complete installation is taken from the 115,000-volt 3-phase 60-cycle lines and stepped down to 4,800 volts before it enters the power area building and is connected to the metal-clad switchgear. Figure 13 shows the operators' console for the Cornell variable density wind tunnel.

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sure treatment with creosote or with solutions of creosote and pentachlorophenol is not feasible or does not seem necessary for the conditions of service to which the crossarms are exposed.

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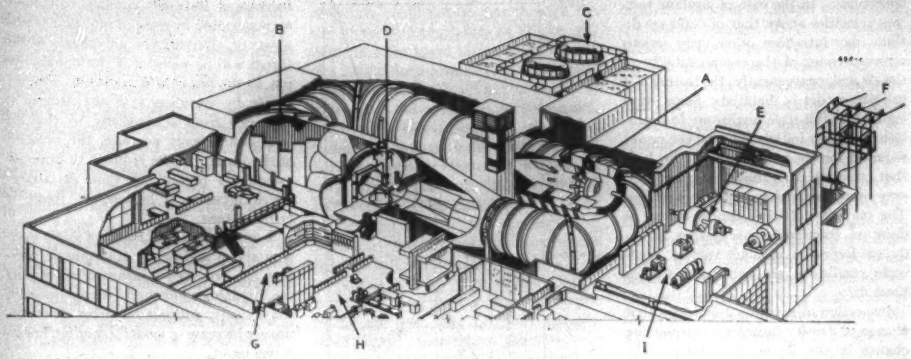


Figure 1. Cutaway view of Cornell Aeronautical Laboratory showing wind tunnel installation

A—Fan impeller
B—Heat exchanger
C—Cooling tower
D—Airplane model in test section
E—10,250-horsepower driving motor
F—115,000-volt 60-cycle power supply
G—Control room
H—Dynamometer room
I—Adjustable frequency system

For operation of powered models in the working section of the tunnel, an adjustable frequency system with frequency adjustment over a range from 60 to 450 cycles per second is arranged for remote operation from the control room. Precision metering of this variable frequency power supply is provided for indication and recording in the control room. The motors used in the powered models are calibrated on induction-type dynamometers capable of testing model motors up to speeds of 27,500 rpm, and up to maximum horsepower ratings of 200. Additional details of the electric equipment briefly mentioned in the foregoing will be given later in this paper.

Aerodynamic Principles Determining Power Requirements of Tunnel

Some knowledge of the aerodynamic principles influencing the design details of the tunnel is necessary for correct application of electric equipment on an installation of this type, although it is the intention of this paper to dwell on the electrical phase of the subject.

The primary object of all wind tunnels is to perform tests on scale models, which tests will produce data to assist the airplane designer in his design of new airplanes or in modifications of existing designs. For this purpose the wind tunnel is designed to measure accurately the reactions on the model at various attitudes and in an adjustable velocity uniform air flow. Various forms of tunnels have been designed[1] to produce effectively this adjustable uniform air flow through an experimental section in which the model is mounted, but the majority of recently designed tunnels built for testing in air velocities up to the speed of sound follow the general geometry of that shown in Figure 2. Force and moment reactions on the airplane model (and the coefficients derived from these) correspond to similar information on the full-size airplane, only if the model is geometrically similar to the full-scale design and also only if the model test is made at a Reynolds number equal to that expected on the full-size airplane in flight. Remembering that Reynolds number

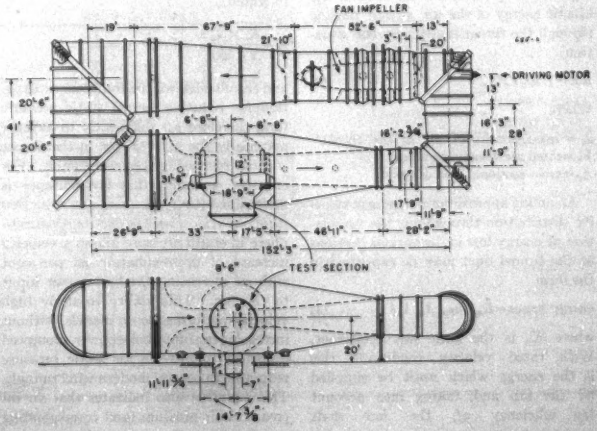
$$R = \frac{Vl\rho}{\mu} \qquad (1)$$

in which

V = relative velocity between body and fluid
l = a characteristic dimension of the body
ρ = mass per unit volume of the fluid
μ = coefficient of viscosity of the fluid

it can be seen that for testing in an atmospheric pressure tunnel, the Reynolds number for flight conditions can be equalled only by using a full-scale model, or alternatively testing a fractional scale model at higher velocities than flight

Figure 2. Outline of wind tunnel structure



conditions. In the case of airplane testing, velocities above that of flight conditions may introduce other more serious errors because of the compressibility of the air and, consequently, the testing of a full-size model is dictated. Some wind tunnels for full-scale testing are in operation, but their initial costs and the power required for their operation are so high that, to date, they have been installed only by centralized government agencies. The majority of wind tunnel testing is done on fractional scale models at reduced Reynolds number values; full-scale conditions are extrapolated from these data.

Inspection of equation 1 indicates that change of density causes a corresponding change in the Reynolds number. The density is proportional to the air pressure, and the viscosity is approximately independent of pressure, so that Reynolds number may be changed approximately proportional to the pressure. A wind tunnel taking advantage of this feature was first built and operated by the National Advisory Committee for Aeronautics at Langley Field, when a relatively small tunnel operating with compressed air at 20 atmospheres pressure was put into operation in 1927. This feature also was incorporated in the design of the tunnels recently built by the Curtiss-Wright Corporation (now the Cornell Aeronautical Laboratory), the California Institute of Technology, and by the National Advisory Committee for Aeronautics at Ames Aeronautical Laboratory, Moffett Field, Calif.

Consider now the power requirements for wind tunnels: Corresponding to a specific air velocity through the working section (throat) of the tunnel, the kinetic energy of the air stream passing through the throat is given by the equation:

$$KE = 1/2\rho_o V_o^2 A_o \qquad (2)$$

Where

ρ_o = mass density of air in the throat
V_o = rated air velocity at throat
A_o = cross-sectional area of throat

Assuming approximately uniform velocity distribution throughout, the summation of energy loss in the various portions of the tunnel duct may be expressed in the form

$$\text{energy losses} = K_o 1/2\rho_o A_o V_o^3 \qquad (3)$$

where K_o is the basic loss coefficient. With rated velocity conditions, this is the energy which must be supplied by the fan and, taking into account fan efficiency ηf, the fan shaft power input is given by the equation

$$\text{hp} = \frac{K_o 1/2\rho_o A_o V_o^3}{\eta f \times 550} \qquad (4)$$

From equation 4 it can be seen that for a fixed throat cross section, the horsepower delivered from the main fan drive will be

$$\text{hp} = \frac{K\rho_o V^3}{\eta f} \qquad (5)$$

in which

$$K = \frac{K_o \times A_o}{2 \times 550}$$

and from which will be found an explanation for reducing tunnel static pressure (and therefore ρ_o) sufficiently to increase materially the air velocity in the throat without increasing the power input. For example, assuming that fan efficiency is maintained (by pitch change) a reduction from one atmosphere to one-fourth atmosphere in static pressure allows a velocity increase of approximately 58 per cent without increasing the horsepower input to the fan. This ability to study high velocity performance on models, without increasing fan input horsepower, prompted designers to provide for static pressure reduction in several modern wind tunnels. This equation also indicates that an increase in air pressure (and corresponding increase of Reynolds number) calls for a corresponding increase of fan shaft horsepower or, alternatively, air velocity at the throat will be reduced if horsepower input to the fan is held constant. For example, by equation 4, if the density is increased from atmospheric to that at four atmospheres pressure, the velocity at the throat will be reduced to approximately 63 percent of that at atmospheric pressure, if horsepower input is held constant.

Summarizing, the change of static pressure above and below atmospheric pressure has provided a means of increasing the Reynolds number and the air velocity, respectively, without requiring a proportionate increase of model size or fan horsepower input.

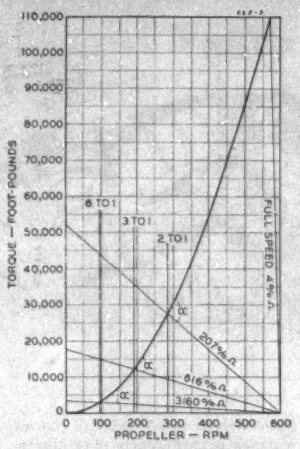


Figure 3. Speed-torque characteristics of 12,000-horsepower 570-rpm fan load

Values of secondary resistance required with a single speed slip ring motor for 2:1, 3:1, and 6:1 speed reduction also are shown

Selection of Main Drive

Wind tunnel power plants can and do take many forms, depending upon the type of tunnel to be powered, and the purchaser's preference. In this particular instance we are considering electric drive, and as the tunnel is of the two dimension or variable density type, with single rotation, the propeller drive unit will be mounted outside the tunnel proper—a construction detail which simplifies greatly the problem of the motor design. Also, power requirements are quite moderate, therefore permitting the use of any of the various types of drives.

The slip ring induction motor is perhaps the least expensive variable speed electric motor unit. This machine, with resistance in the secondary winding, has series characteristics, the speed being a function of secondary resistance and shaft torque.

The conventional propeller system has a torque characteristic which varies as the square of the speed for any established blade angle and air density. At rated speed, torque is, of course, 100 per cent, while at half speed it is 25 per cent. Usually the minimum requirement for speed range is 6 to 1, with the torque requirement at one-sixth speed equal to approximately three per cent. This is, of course, far outside the practicable operating range of a single speed slip ring motor. As a matter of fact, it taxes the performance of a two speed or pole changing motor with a two to one synchronous speed, and a horsepower range of the order of 8 to 1.

Such two speed drives have a point of discontinuity at the speed change point. They also require two slip regulators. With induction motors the speed varies

with change of applied voltage for a particular setting of secondary resistance and the propeller torque varies with changes of the model attitude, or change of model size in the test section. Corresponding to a change in load torque the induction motor speed will change, and the amount of change varies widely according to the amount of resistance in the secondary circuit. This type of motor inherently operates at low power factor, especially when lightly loaded. Because of these characteristics this combination of machines has not found complete acceptance on the part of wind tunnel operators. Economics, of course, play a major role in any large program of this nature, and the consultants for the subject project wished to retain the economies of the induction motor drive for maximum power requirements, and supplement the single speed induction motor with some different type of speed control between minimum speed and half speed.

One of the fundamental tunnel specifications was a 10 to 1 speed range which obviously could not be met through the use of the slip regulator, as will be evident from the speed torque requirements of a 12,000-horsepower 570-rpm propeller system (Figure 3). The parabola, of course, is the propeller torque curve, while the straight lines are the speed torque curves of the induction motor with various secondary resistances, with resistance values in per cent. The angle of the intersection (α) decreases rapidly below 50 per cent speed. The slip regulator, however, should function successfully between half speed and full speed.

Various systems were studied, but it was found to be most economical, for the rating involved, and yet fully reliable, mechanically, to combine the two basic adjustable speed drives, that is to combine an adjustable voltage (Ward Leonard) drive, with the slip ring motor and slip regulator to form a tandem drive. The adjustable voltage drive is operating alone over the range of 10 per cent to 45 per cent speed, while between 45 per cent and 100 per cent speed, both drives share the load: the d-c equipment providing the vernier control, so to speak, and the induction motor with its slip regulator the coarse adjustment.

The basic power requirement for the tunnel was set at 12,000 horsepower at 570 rpm for 30 minutes, the use of adjustable pitch propellers permitting this specification to fit into any tunnel pressure or air density. The power requirements of the conventional propeller vary as the cube of the speed. Thus, at half speed, or 285 rpm, the torque is reduced to 25 per cent rated, and the horsepower to 12.5 per cent or 1,500 horsepower.

The d-c part of the drive, as noted previously, provides the entire power to the propeller up to 45 per cent of rated speed, or 260 rpm. The motor rating of 1,250 horsepower (continuous) is more than ample to meet this requirement. Speeds

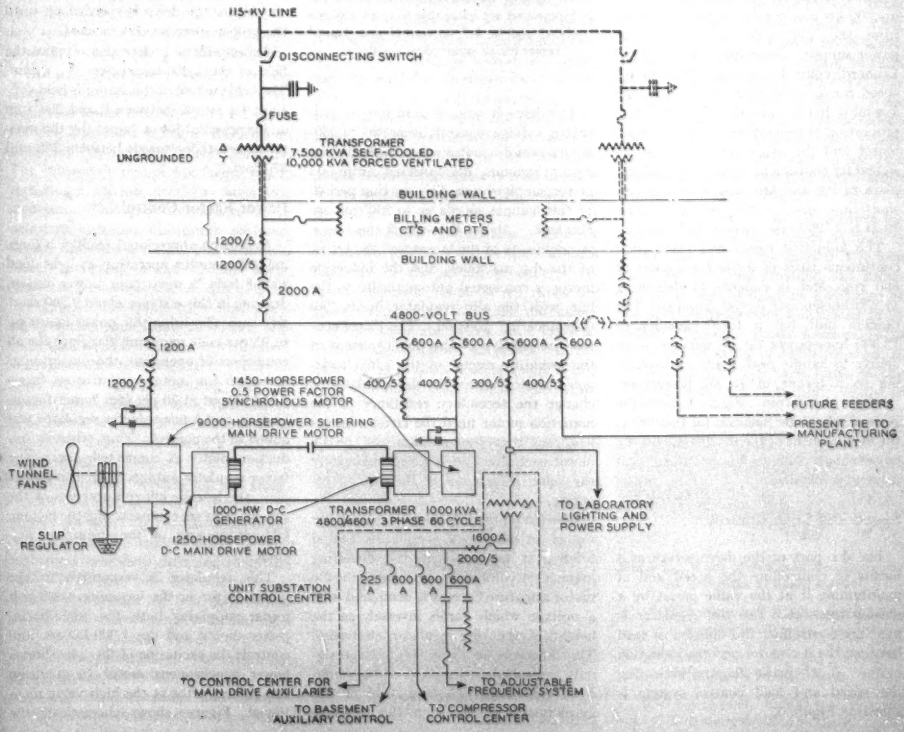


Figure 4. Schematic diagram of power circuits of the fan drive of the Cornell Aeronautical Laboratory

Figure 5. Motor room of Cornell variable density wind tunnel

In background is 4,800-volt metal-clad switchgear and main drive control. In center is 10,250-horsepower continuous rated tandem motor set and 1,000-kw motor-generator set. In foreground are adjustable frequency system machines and on left its control and control center for all motor room auxiliaries

higher than 260 rpm are provided by motor field weakening, at constant generator voltage; that is, constant horsepower (1,250 horsepower) is available throughout the range 260–570 rpm.

Power to this d-c motor is derived from a 1,000-kw motor generator set operating from the 4,800-volt 3-phase 60-cycle power supply. Generator voltage (Ward Leonard) control is used to obtain motor speed range 0–260 rpm. Obviously, the available horsepower then is reduced in proportion to generator voltage. The d-c motor and the motor generator are designed for continuous duty at their nameplate rating and are capable of carrying short-time loads of 200 per cent rating (that is 2,500 horsepower at full voltage).

The induction motor was rated on a continuous basis of 9,000 horsepower at 590 rpm and is capable of delivering 11,250 horsepower for 30 minutes. The tandem unit has a total capacity of 12,500 horsepower for 30 minutes, with ability to handle peak loads corresponding to a torque of 15,000 horsepower (torque) at 570 rpm. Figure 4 shows the general schematic diagram for this drive, the arrangement of the machines, and the power supply. Figure 5 shows the tandem drive unit installed.

Speed and Load Control

The d-c part of the drive serves as a means of controlling the speed and of maintaining it at the value preset by a master rheostat. The slip regulator is used for controlling the division of load between the d-c motor and the induction motor. A schematic diagram indicating the speed and load control system is shown in Figure 6.

The drive is started from rest by generator voltage control using the 1,250-horsepower d-c motor only; the induction motor remains disconnected from its power supply during this starting period. In this manner speeds up to 260 rpm are obtained. Above this speed the power requirements of the fan exceed the rating of the d-c machines, and the induction motor is connected automatically to the line with the slip regulator in its "all resistance in" position. The "load control" responsive to the direct current in the armature circuit of the 1,250-horsepower motor causes the slip regulator to change the secondary resistance of the induction motor until the latter assumes load such that the a-c motor and the d-c motor each are loaded to approximately the same percentage of their rated capacity.

The load proportioning is effected by use of an amplidyne regulator. Stated briefly, it operates in the following manner: A voltage proportional to the d-c motor armature current is compared with a voltage which varies inversely as the height of the slip regulator electrodes. The difference of these two voltage signals is applied to the field of an amplidyne generator. The armature of this amplidyne is connected to the armature of a separately excited shunt wound d-c motor driving the slip regulator electrodes up or down. This increases or decreases, respectively, the secondary resistance of the induction motor causing it to transfer load to or from the d-c motor until the two signal voltages are equalized, and the electrode motor stops.

The speed of the drive is maintained by means of an electronic-amplidyne regulator as follows: The drive is equipped with a permanent (Alnico) field tachometer generator. Its voltage is compared with a potentiometer connected across a regulated 125-volt d-c reference source. The position of this potentiometer determines the speed at which the drive operates.

The difference between the voltages of the tachometer generator, on the one hand, and the potentiometer, on the other hand, is applied to the grid of an electronic tube. Thus amplified, this voltage then is applied to the regulating field of an amplidyne exciter. The latter controls the voltage of the 1,000-kw d-c generator, and regulates speed to preset values throughout the speed range. Thus, if the tachometer voltage is lower than it should be, the drive is speeded up until the proper speed level is reached.

An amplidyne exciter also supplies the field of the 1,250-horsepower d-c motor. The field current of this motor is held constant for speeds between 0 and 260 rpm and is preset at lower values (by the master rheostat) for speeds between 260 and 570 rpm.

Power Factor Control

As will be appreciated readily, a large induction motor operating at light load would have a very poor power factor, drawing in this instance about 2,200 reactive kva. To bring this power factor up to 95 per cent minimum (lagging) for all conditions of operation, the synchronous motor on the motor generator set has a rated output at 50 per cent power factor, leading, and a power factor regulator was added to the control. Thus, when the induction motor is connected, the power factor regulator automatically comes into play, the leading kilovolt-amperes of the synchronous set counteracting the lagging kilovolt-amperes of the induction machine.

This regulator is responsive to the power factor in the incoming 4,800-volt feeder supplying both the 9,000-horsepower motor and the 1,000-kw set and controls the excitation of the 1,450-horsepower synchronous motor to maintain this power factor at the high value mentioned. Figure 6 shows schematically the

elements of this system and indicates that the 1,450-horsepower synchronous motor field actually was supplied by a conventional d-c exciter. This in turn is excited separately by an amplidyne exciter, the field of which is controlled by the power factor regulator.

Main Power Supply

The availability of an adequate power supply is an important consideration in determining the location of an installation of this type.

The power system must be selected to handle high intermittent loads corresponding to full power running of the tunnel, although total energy consumption is comparatively small. For example, the Cornell tunnel will have 20-minute peaks of approximately 10,000 kva which will occur when running the tunnel at top air speed. Such tests would consume perhaps ten per cent of the running time of the tunnel, while the majority of tunnel tests will have power demands of less than half this value. It will be remembered that the power required varies as the cube of the air speed; for example, a half speed test in the tunnel requires only one eighth the power of a full speed run.

An adequate power supply for the Cornell tunnel is provided by a short overhead stub feeder from the 115-kv 3-phase 60-cycle transmission line of the Niagara Lockport and Ontario Power Company. The laboratory end of the feeder line is terminated on an outdoor substation structure. This structure mounts 115-kv manually-operated disconnect switches, thyrite lightning arresters, and boric acid fuses, connected ahead of the transformer as shown by the schematic diagram in Figure 4. The transformer is a 3-phase oil-immersed unit rated 7,500-kva self-cooled, or 10,000-kva forced ventilated. It steps down the voltage from 115 kv to 4,800 volts. The ventilating fans are started automatically as a function of transformer temperature or whenever the tunnel fan drive is run above a predetermined speed.

The secondary winding of the transformer is throat connected through the wall of the wind tunnel motor room, at first floor ceiling height. After passing through a secondary metering room the 4,800-volt copper tube bus connection is carried up through the first floor ceiling directly into an incoming feeder unit of a metal-clad switchgear line-up. Figure 4 shows, diagramatically, the electrical layout of the 4,800-volt switchgear, the air circuit breaker ratings, and the provision for future extension of the system.

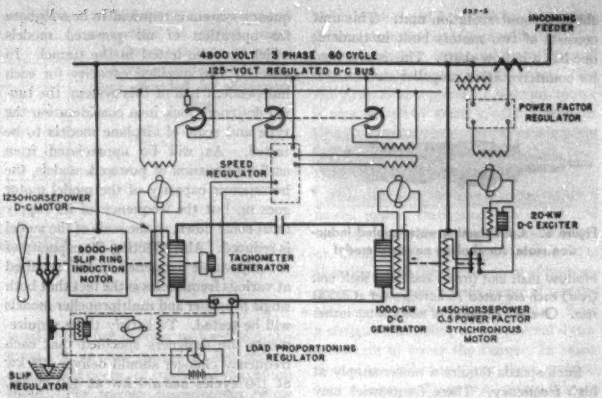


Figure 6. Elementary diagram showing speed-load, and power factor regulating features, incorporated in control of fan drive

Powered Model Testing

It has been pointed out how the force acting on a model airplane may be measured in the test section of the wind tunnel. The lift and drag, of course, are determined readily, but the behavior of the airplane under the resultant forces imposed by its power plant have not been determined. These forces may be provided by building a power plant in the model airplane. An electric motor is used in place of the gasoline engine. The model, of course, will be an exact scale model. If this model is one tenth the size of full-scale model, the propeller will be one-tenth the diameter of the actual propeller. Its speed, therefore, must be ten times the speed in order to maintain the model propeller tip speed at the same value as that of the full-scale propeller. If the rated speed of the actual propeller is 900 rpm, the model must run at 9,000 rpm, and power requirements are reduced inversely as the square of the scale.

The high frequency motors used for this purpose are quite special. Space limitations are usually quite severe. Consider, for instance, the one-tenth scale model. If the nacelle frontal diameter is 40 inches, the model can be but four inches. If the output of the full-scale engine is 1,800 horsepower, the model must be 18 horsepower. It is then no mean task to build an 18-horsepower motor with a diameter of four inches. Motors of this type are water-cooled; that is, the frame includes a water jacket. Air cooling is not practicable because the discharge of air produces a jet effect, and this would affect the accuracy of the results.

Model motors are almost without exception tailor-made. Speeds as high as 80,000 rpm at 0.1-horsepower $1^1/_4$-inch diameter have been provided, and horsepowers as high as 3,000 at 2,400 rpm at the other extreme with a diameter of 29 inches. Figure 7 shows some of these machines. A motor of 300 horsepower at 20,000 rpm also has been built, in the type of construction shown. Figure 8

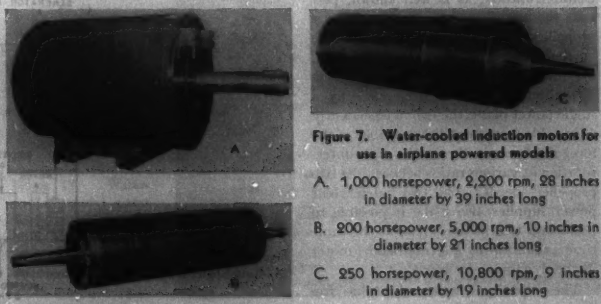


Figure 7. Water-cooled induction motors for use in airplane powered models

A. 1,000 horsepower, 2,200 rpm, 28 inches in diameter by 39 inches long

B. 200 horsepower, 5,000 rpm, 10 inches in diameter by 21 inches long

C. 250 horsepower, 10,800 rpm, 9 inches in diameter by 19 inches long

shows a counterrotation unit. This unit consists of two motors built in tandem; one has a hollow shaft. This is provided for counterrotation propeller studies.

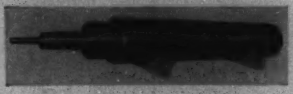


Figure 8. Contraturning water-cooled induction motor for airplane powered model

Hollow shaft unit (front) and solid shaft unit (rear) each are rated 75 horsepower at 3,000 rpm. Over-all diameter of motor is ten inches

Such speeds require a power supply at high frequency. These frequencies may be obtained with alternators, or frequency converters. Reference to Figure 9 will show, at the top, a 5-unit set driven by a 400-horsepower 1,200-rpm synchronous motor, operating from the 440-volt 60-cycle supply. The alternators *A* and *B*, each rated 156 kva, 440 volt, 60 cycle, furnish power to frequency converters *A* and *B*, respectively. The d-c generators *A* and *B*, each rated 100 kw, 250 volt, supply power to 140 horsepower 960/1950-rpm d-c motors driving, respectively, these converters *A* and *B*. By varying the voltage of generators *A* and *B*, the speed of the converters *A* and *B* is adjusted. In this manner, the converters, receiving electric power at 60 cycles at their collector rings, change it to 60/450 cycles at their stator output. This output is used to operate the model motors at the required high speed. The voltage of this output is regulated by controlling the field of the corresponding alternator *A* or *B*.

With two independent frequency converters available, it is possible to operate them either in parallel, or separately, at different frequencies. This arrangement also readily permits studies in counterrotation of model motors and propellers. Counterrotation, as is well known, permits the use of smaller propellers, that is propellers with less sweep, and the torque on the airplane balances out. Although, in practice, contrarotating propellers have been driven, through gears, by a single power plant, the two independently adjustable power supplies described in the foregoing permit the study of counterrotation at various ratios between the two propeller speeds. The two independent power supplies also make it possible to perform a test in the tunnel at the same time as calibrating a second model motor in the dynamometer room.

The capacity of the adjustable frequency system is required to be adequate for operation of all powered models which may be tested in the tunnel. In selecting the specified capacity for each independent half of this system, the tunnel designers took into consideration the type and scale of airplane models to be tested. As will be appreciated from earlier discussion of powered models, the horsepower capacity of the model motor goes up but the frequency of its supply must come down, as the scale of the model is reduced. Also affecting the capacity of the adjustable frequency system required at various frequencies is the fact that both single propeller and multipropeller models will be tested. To satisfy these requirements the designers specified that each frequency changer should deliver 125 kw at 150 cycles and 50 kw at 450 cycles. The induction frequency converter designed to meet the first requirement has a capacity of 375 kw at 450 cycles. While each converter is inherently oversize at the high frequency, the driving motor of each frequency changer set can be selected to meet more exactly the requirements without excess capacity. The d-c driving motor of each frequency changer set is rated 140/75 horsepower 950/1,950 rpm at 250 volts. It is started from rest by generator voltage control, and operated in this manner up to 950 rpm. The frequency output of the converter which it drives varies correspondingly from 60 cycles to 250 cycles. Above this point the generator voltage is maintained at 250 volts, while the d-c motor speed is increased to 1,950 rpm by weakening its field. Frequency of the converter output varies correspondingly from 250 to 450 cycles. Under these conditions of operation the d-c motor load increases from 0 to 140 horsepower at 950 rpm, then decreases gradually from this speed to 75 horsepower at 1,950 rpm.

As pointed out in the foregoing, large model motors are required to operate at low frequency, and in order to keep the motor leads as small (and therefore as flexible) as possible it is normal to design the windings of these motors for a higher voltage per cycle than the higher speed smaller motors. On the other end of the range extremely high-speed small motors operating at, perhaps, 450 cycles, require a winding designed for low voltage per cycle in order to avoid excessively high voltages and mechanically fragile wire. Although national standards are not established, normal practice is to design model motor windings for operation at one of the following values of volts per cycle: 0.625, 1.25, or 3.75. This accepted practice imposes a further requirement, of wide voltage range, on the adjustable frequency power supply. To satisfy this requirement each frequency converter is arranged for reconnecting the stator winding to operate either as a single circuit delta or double circuit delta machine.

This power supply equipment is unique in that electronic control is used on the generator field, motor field, and the converter exciter (alternator) field. Such control is new, of course, only in this particular field, it having been applied successfully on wind tunnel main drives where very special characteristics were desired. It also has been used on many other industrial drives. This type of control saves space and lends itself readily to the extreme flexibility needed for a laboratory tool of this type.

A unique feature incorporated in this installation, and made possible by the electronic control, is a volts-per-cycle regulator of the converter output. This is of extreme value in the operation of model motors because of the need to operate nearer to the flux saturation point in this design of motor

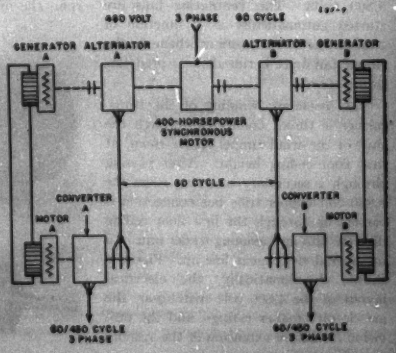


Figure 9. Schematic diagram of adjustable frequency supply system

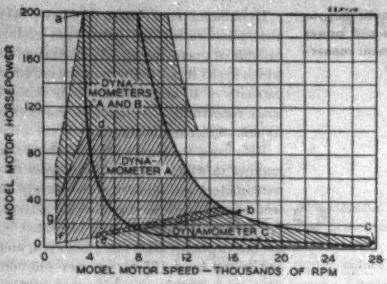


Figure 10. Horsepower-speed envelope of model motor maximum ratings to be tested on dynamometers, and coverage provided by dynamometers

than in more conventionally designed induction motors.

Model Motor Calibration

When testing a powered model in a wind tunnel it is, for aerodynamic reasons, necessary to control accurately the power delivered to the model propellers, according to the lifting force on the airplane model, as indicated by the wind tunnel balance system. The power input to the propellers may be determined either by direct torque and speed readings or by deduction from the electric power input to the model motors. The Cornell installation is equipped to use the latter method. In this method it is first necessary to calibrate the model motors for mechanical power output versus electric power input over the full range of torque and speed through which the motors can operate safely. A cradled dynamometer to perform this calibration for a specific motor presents no new problems but the selection, design, and manufacture of dynamometer equipment which will calibrate accurately all model motors to be used in one wind tunnel calls for many special features.

The selection of adequate capacity, range, and flexibility in the dynamometer installation must depend largely on the aerodynamicists' advice of what powered models can be tested in the tunnel, and his predictions of what will be tested. Based on such information, the design consultants for the Cornell tunnel defined an envelope of maximum horsepower and speed ratings of model motors to be calibrated on the dynamometer installation. This envelope is shown in solid lines in Figure 8. Specifications for calibrating equipment also required that, for any specific motor with maximum rating falling anywhere within the afore-mentioned envelope, the motor maximum torque be indicated accurately to within plus or minus one-quarter per cent. For a model propeller driving motor the maximum torque and maximum horsepower output will occur, of course, at maximum speed. For torque measurement below the maximum output it is desirable to indicate torque with an absolute error not greater than that corresponding to one-quarter per cent of the torque at maximum output of the motor on test.

It is also necessary to be able to calibrate all motors over a wide range of speed and torque. In Figure 10, a point *d* represents the maximum output of a motor for which calibration is required. The area *d, e, f, g,* indicates the full range of speeds and torques for which calibration of this motor is required.

Consideration of a few points in the envelope shown in Figure 10 gives a better conception of the total range of torques for which calibration equipment must indicate accurately. Consider the 200-horsepower 3,500-rpm model motor represented by point *a*. Its torque at maximum output is approximately 300 foot-pounds and it should be calibrated down to 30 foot-pounds torque. Then the 35-horsepower 16,000-rpm model motor is represented by point *b*. Its torque at maximum output is approximately 11.5 foot-pounds and it should be calibrated down to 1.15 foot-pounds torque. Finally the 2-horsepower 27,500-rpm motor is represented by point *c*. Its torque at this maximum rating is approximately 0.38 foot-pounds and it should be calibrated down to 0.038 foot-pound torque.

It is desirable to calibrate completely a model motor, throughout its speed and torque range, on a single dynamometer or, at most, on two dynamometers. On theother hand, the requirement of high accuracy over such a wide range of torques and speeds makes it desirable, from a design standpoint, to use several dynamometers to cover the range. In selection of machines to cover these requirements, consideration was given first to eddy current inductor-type dynamometers. In this design, mechanical power input to the dynamometer is converted into eddy current losses within the machine. These losses are removed from the machine by cooling water conducted to and from the cradled machine by flexible hoses. It is obvious that this type of machine can absorb only mechanical power and that the minimum torque which it can measure is that required to overcome friction and windage losses within the dynamometer. Although machines of this type are suitable for model motor testing from the standpoint of speed and required capacity, friction and windage are higher than desirable from the viewpoint of precision testing. Also, the necessity of cooling water hose connections is a handicap to attaining the required accuracy of torque measurement on this installation.

On the basis of using three dynamometers to cover the complete envelope of

Figure 11. Water-cooled model motor being calibrated on a 35-horsepower 15,000/27,500-rpm induction-type dynamometer

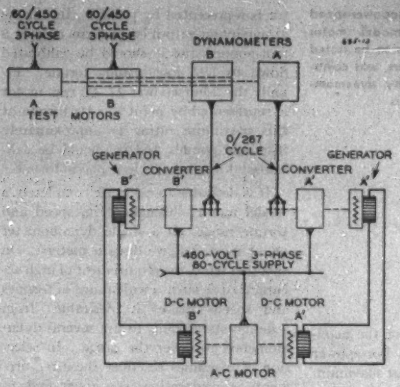


Figure 12. Schematic diagram of dynamometers and power absorption equipment connections

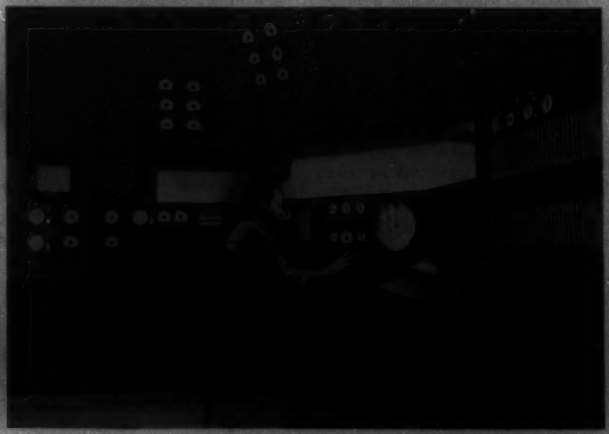
requirements, design studies indicated friction and windage losses to be in excess of the minimum torque values to be measured. Apart from any other considerations, this called for some means of supplying electric power to the stator of the dynamometer to compensate for the friction and windage losses. The substitution of induction-type machines in conjunction with adjustable frequency absorption equipment satisfies these requirements.

The induction-type dynamometer used consists of a squirrel cage induction motor with the stator cradled in oscillating trunnion bearings. Connections to the stator windings are made through mercury cups in order to minimize inconsistent interference which would reduce the precision of these instruments. These dynamometers act as induction generators, or in some cases (as explained later) as induction motors, and heat to be removed represents no more of a problem than in conventionally designed induction motors of equivalent rating. Ventilation is provided by constant speed blowers mounted on the cradled dynamometers, and connections are carried through mercury cups.

Reference to Figure 10 shows, by the shaded areas, the manner in which three cradled induction dynamometers were selected to cover the envelope of horsepower speed requirements for this installation.

Dynamometer *A* has a 100-horsepower absorption rating over a speed range of 3,500 rpm to 10,500 rpm. It is of solid shaft construction and when used, alone, will operate up to 16,000 rpm, at which speed the absorption capacity required is 30 horsepower. It also may be operated with dynamometer *B* either in tandem or for testing of contraturning model motor units. For either of the latter two mechanical arrangements, top speed is limited to 13,000 rpm, at which speed dynamometer *A* has the required capacity of 55 horsepower. Dynamometer *B* has a 100-horsepower absorption rating over a speed range of 3,500 rpm to 10,500 rpm. It is of hollow shaft construction, arranged for use with dynamometer *A*, either in tandem or for testing of contraturning model motor units. Under either of these conditions it may be operated up to a maximum speed of 13,000 rpm, at which speed it has the required capacity of 55 horsepower.

Figure 13. Operators' console in control room of Cornell variable density wind tunnel



Dynamometer *C* has a 35-horsepower absorption rating at 15,000 rpm and is capable of operating up to 27,500 rpm, at which speed it has more than the required capacity of 10 horsepower. It is of solid shaft construction. Figure 11 shows this dynamometer installation.

Reference to Figure 12 will show the manner in which the 100-horsepower dynamometers are connected electrically to feed energy back to the 60-cycle system. D-c motors A' and B' each are rated 60 kw (absorption), 250 volt, 1,800 rpm, and are driven by a 125-horsepower 440-volt 60-cycle squirrel cage induction motor. Induction frequency converters A' and B' each are rated 70-kw absorption and each connected to a 75-horsepower (input) 250-volt 500/1,800-rpm d-c generator. Each of the dynamometers *A* and *B* are of 2-pole construction and their synchronous speed frequencies corresponding to a speed range of 1,125 to 16,000 rpm are between 18 and 267 cycles. The converters A' and B' are designed to receive power on the slip rings over this frequency and, by varying the speed of d-c generators A' and B', deliver power from the stator to the 60-cycle system. The speed of generators $A'B'$ is changed between 0 and 500 rpm by armature voltage control. Above this value, armature voltage is maintained at 250 volts and speed is increased to 1,775 rpm by field weakening. At this point frequency on the converter slip rings is 267 cycles corresponding to 60 cycles at the stator terminals.

Consider the method of operating this system to calibrate test motor *A* on dynamometer *A*. The constant speed set, of

which motor A is a part, first is started by connecting the 125-horsepower a-c motor to the 440-volt 60-cycle line. Converter A' with stator winding connected to the 60-cycle line then is started from the d-c end in the same direction of rotation as its magnetic field. The speed of this set is raised by armature voltage control until the frequency on the slip rings of the converter is about five or ten cycles. At this point dynamometer A, with its model motor mechanically connected but electrically isolated, is connected electrically to frequency converter A'. The frequency applied to dynamometer A then is raised by first lowering the speed of the converter close to zero revolution per minute, then reversing it and raising the speed in the opposite direction. When the desired minimum test speed for the model motor is reached, its supply frequency will be matched, and the motor will be connected to its supply. Incidentally, this procedure for connecting the model motor to its supply also is followed for a model motor in the tunnel. In this case the model propeller with its motor is "windmilled" by the tunnel air stream, and the power supply must be matched to the motor speed before connecting it to the motor. In order to load the "test" motor, while its speed is held constant by its power supply, it is merely necessary to slightly lower the frequency at the terminals of dynamometer A. This is accomplished by vernier adjustment of the field of motor A.

The 35-horsepower dynamometer is operated in a similar manner by connecting it to a suitable adjustable frequency source.

Conclusion

These are some of the problems to be considered in the application of electric equipment for an installation of this magnitude. There are, of course, many others. However, this indicates to some degree their nature and complexity. More than that, it demonstrates how important is the correct selection of electric equipment.

Other laboratory facilities will have comparable problems, but electrical engineers will find that all demand the same approach. A careful analysis must be made, a practical, thorough, and detailed study of the performance expected by the scientists who are going to operate the new instrument.

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F-3 Lead Alloy—An Improved Cable Sheathing

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OPERATING EXPERIENCES have demonstrated that the attainment of good service reliability of most electric power cables has become substantially more a function of the characteristics of the sheath than of the insulation. Modern underground installations of impregnated-paper-insulated, lead-covered power cable include

1. Solid-type cable with
(*a*). Compound-filled joints without reservoirs.
(*b*). Oil-filled joints with reservoirs.

2. Oil-filled cable operated at 10- to 15-pound gauge pressure.

3. Gas-filled (or pressure) cable operated at
(*a*). Low pressure (10- to 15-pound gauge).
(*b*). Medium pressure (24- to 40-pound gauge).
(*c*). High pressure (150- to 300-pound gauge).

Aerial installations, in which the cable is suspended by rings to a messenger strung between poles, consist generally of the same basic cable designs.

Depending upon the type of cable and installation, modern requirements for lead sheath include some or all of the following properties in addition to the time-honored criteria of strength, ductility, hardness, "cleanliness," and concentricity:

1. Resistance to slow bending fatigue resulting from movement in the manholes caused by expansion and contraction during daily load cycles.

2. Resistance to creep (expansion) at low internal pressures (10- to 30-pound gauge).

3. Resistance to burst caused by high internal pressures developed at the bottom of slopes and vertical risers, in pressure-type cable systems, and in solid-type cable systems having reservoirs of oil, connected to the joints.

4. Resistance to abrasion caused by installation and movement in ducts.

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The authors are indebted to many of their engineering associates who have assisted in the test program and preparation of this paper and wish to make specific acknowledgments to A. A. Jones, Anaconda Wire and Cable Company, and G. B. Johnson, International Smelting and Refining Company.

5. Resistance to vibration fatigue caused by traffic on any type of installation and by wind on aerial cable.

6. Stability from age-hardening or self-annealing so that the foregoing properties are retained throughout the life of the cable and so that the cable can be withdrawn from ducts and reinstalled without cracking the sheath.

7. Workability, which facilitates melting and extruding as sheath with sound welds and uniform composition.

8. Corrosion resistance.

Some commercial grades of lead have given satisfactory service in a great many installations, especially up to about 20 years ago. The sheaths have become increasingly the limitation[1-5] on the serviceability of power cable with the advent of the following:

1. Decrease in viscosity of impregnating compound.

2. Use of oil reservoirs connected to joints.

3. Improvement in thoroughness of insulation impregnation.

4. Increase in maximum allowable temperatures for normal operation.

5. Establishment of still higher temperatures for emergency operation.

Item 5 was the last to occur, and its use has accentuated the need for an improved cable sheathing.

Numerous lead alloys have been developed to overcome these difficulties, but each, it seems, is lacking in one or more important property.

Antimony alloy (0.75 to 1.0 per cent) has poor creep resistance[6] and undergoes change in properties with age,[7] including loss in ductility.

Tin alloy (two per cent) has relatively poor creep resistance[6] and about the same or slightly better resistance to vibration fatigue than the best commercial grades of lead (refer to Figure 13).

Cadmium-antimony and cadmium-tin alloys, known as BNF alloys, offer extrusion difficulties, age-harden, and have poor creep resistance.[8]

Calcium alloys (0.025 and 0.031 per cent) are difficult to extrude (very drossy) and undergo slow and serious age hardening, which has caused troubles to develop in a few years of service because of brittleness and early cracking in the manholes.[9]

Tellurium alloy (0.05 to 0.10 per cent) tends to segregate in the welds during extrusion and, according to unpublished data, has poor creep resistance.

An Improved Lead Alloy

To satisfy the need for a lead alloy having the desired improved properties, the Anaconda organization instituted a research program to develop a suitable alloy. The best material developed in this program is known as F-3 lead alloy.[10] It is composed of arsenical lead containing small amounts of tin and bismuth. This new material when suitably hardened by heat treatment also has physical properties which may meet the requirements set for medium-pressure gas-filled cable.[11] The sheaths are characterized by their strong tough welds, outstanding resistance to bending fatigue, excellent creep resistance, and bursting strength.

Chemical Composition

The chemical composition used for the F-3 alloy pig metal is

Arsenic (As)	0.15 per cent
Tin (Sn)	0.10 per cent
Bismuth (Bi)	0.10 per cent
Copper (Cu)	Minimum
Antimony (Sb)	Minimum
Lead (Pb)	99.65 per cent

This alloy is extruded in conventional equipment with the same technique employed in handling commercial grades of lead. It is a "clean" alloy not subject to excessive drossing associated with some other lead alloys. This feature results in strong welds and facilitates the making of wiped joints. Beginning early in 1945, a number of large orders of paper-lead cable with F-3 alloy sheath have been produced, shipped, and installed without difficulty.

Bending Resistance

The current carried by a power cable usually varies in a daily load cycle which causes a daily variation in temperature. This variation produces longitudinal expansion and contraction of the cable which accumulates in the manholes where expansion loops are provided. The accompanying daily bending of the cable in the manholes has, in some cases, broken the sheaths. Repairs have not proved very satisfactory, and in many cases replacement of lengths of perhaps 300 to 500 feet of cable has been necessary. For many installations, current-carrying capacity and life of the cable are determined more by the ability of the sheath to withstand such slow bending than by the ability of the insulation to withstand the voltage.[9,5]

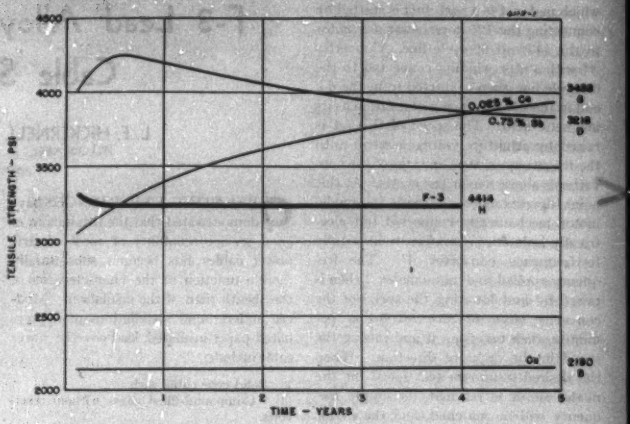


Figure 1. Age hardening
Room temperature

Tests have been conducted on the bending of various types of cable at room temperature and elevated sheath temperature. The results obtained on accelerated cyclic bending, 0.5-inch cable movement at each duct mouth, indicate that the life of F-3 sheath is between three and four times the life of copper-bearing lead sheaths on the same kind of cable.

Abrasion Resistance

A large majority of underground cables in this country are pulled into ducts. In recent years increasingly longer lengths and larger and heavier cables have been used. In some cases as much as seven tons or more of cable have been installed in one pull. Irregular ties or pebbles in the ducts cause scoring of the sheath. Also, it is subject to bruises in handling and working around it. After it is installed, expansion and contraction with daily changes in temperatures cause continual movement during the life in service.

In aerial cable, abrasion resistance is needed, not only to withstand the effects of installation and of cable movement caused by expansion and contraction, but also to minimize cutting of the sheaths at the rings which support the cable.

The most suitable indication of abrasion resistance is the hardness test, although it is recognized that some factors other than those involved in such tests are influential. The relative hardnesses of various lead and lead alloy materials are shown in Table I.

These hardness data apply to extruded material which has aged at room temperature for about three to eight months. Generally, lead alloys grow appreciably harder with age, but the hardness of F-3 alloy remains about the same.

While hardness is desirable to obtain abrasion resistance, the harder materials usually lack ductility and break under tensile stress with very small elongation. Age-hardening materials lose generally in ductility with age, becoming in some cases too brittle for use. The new F-3 alloy has both hardness and good ductility which is retained with age, as is shown later.

Long-Time Aging

The F-3 alloy does not harden with age, as calcium, antimony, and to some extent tin alloys do. Instead of an increase in tensile strength, a slight decrease occurs, as is shown in Figure 1. These data were obtained from tests of water-quenched tubes which were aged and tested at room temperature. Similar results were obtained in tests of sheath removed from cable.

Materials which harden appreciably with age lose ductility, a fact which is

Table I. Hardness of Lead and Alloys
Room Temperature

Sample Number	Material	Brinell Hardness Number
2,264	Desilverized lead—A	3.9
2,180	Copper lead	4.5
2,296	Chemical lead	4.5
3,458	0.025 per cent calcium	8.1
4,414	F-3 alloy	8.4
4,212	2 per cent tin	9.0
1,228	0.031 per cent calcium	10.4
3,218	0.75 per cent antimony	10.4

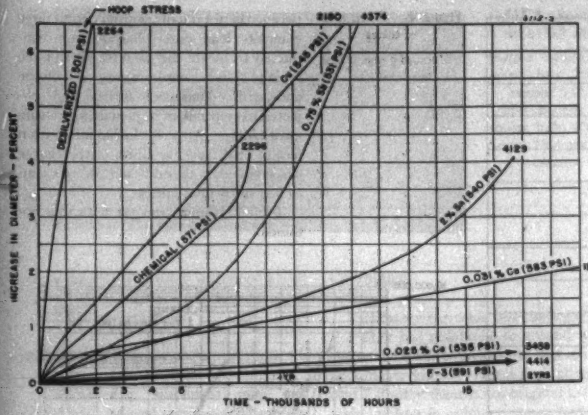


Figure 2. Creep of tubes
61-pound gauge, room temperature

shown by decreasing amounts of elongation to fracture in tensile tests of strips removed from cable sheaths. F-3 alloy has given an elongation to fracture of about 23 to 30 per cent throughout the four or five years during which tests have been made. Further information on this characteristic is given under "Fracture and Ductility."

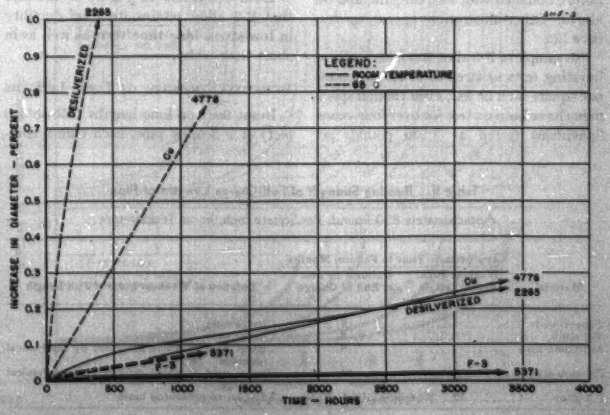
Creep Resistance

Resistance to creep under tensile stress is especially beneficial for sheaths on oil-filled and gas-filled cables and on solid-type cable having a hydrostatic head of oil. In all of these the continuous internal pressure tends to expand the sheath. Under relatively low stress for periods of years, the safe expansion of commercially pure lead sheaths is much less than the 30 to 50 per cent obtained to fracture in short-time tensile tests. It is of the order of three to five per cent. For most of the alloys the elongation that can be expected without fracture is less than that for lead in both short-time and long-time tests.

In solid-type cable having no additional oil available, the sheath is expanded by bending during installation and by thermal expansion of the conductors and insulation within the sheath. Since lead has little elasticity, a large part of the expansion remains as permanent distension of the sheath, leaving a gap on the inside. Void spaces thus are produced which are likely to appear in the insulation. Such voids are detrimental to the electric strength of the insulation in high-voltage cables. Thus good creep resistance is beneficial in obtaining long life for both the sheath and the insulation.

Tube or sheath specimens 15 inches long and without cable inside were sealed with compression fittings and subjected to constant internal oil pressures.[12] The creep (that is, increase in tube diameter) was measured by a special type Al-SR4 strain gauge[12] over a period of from one to five years. This method was found capable of measuring changes in diameter in the order of 0.002 per cent. Test lines were operated at gauge pressures of 61, 42, and 35 pounds at room temperature and at 35 pounds at 65 degrees centigrade.

Figure 3. Creep of tubes
35-pound gauge



Typical data, selected from the 105 samples tested, are shown in Figures 2 and 3 in diameter with time. From Figure 4 in which the data are shown as creep rates, it is evident that F-3 alloy has a creep resistance at room temperature about 45 times that of copper-lead and 25 times that of chemical lead at a stress of about 500 to 600 pounds per square inch and at least equal to any heretofore known lead-alloy sheath material. The curves in Figure 3 for creep at 35 pounds (approximately 300 pounds per square inch hoop stress) indicate that F-3 alloy has about 30 times the creep resistance of copper-lead at room temperature and about ten times that of copper-lead at 65 degrees centigrade.

Fracture and Ductility

Bursting Strength of Tubes

Tube specimens 15 inches long were tested at various stresses and the time required for failure obtained as described by Bassett and Snyder.[13]

Figure 5 shows the data obtained for F-3 alloy and other materials. (This figure is essentially the same as Figure 7 of reference 12 with a few deletions and the addition of new data.)

Data from fracture tests of lead show customarily that at low stresses, such as 400 and 600 pounds per square inch, lead alloys do not have as much advantage over common lead and copper-lead as their tensile strengths would indicate. At higher stresses, such as 1,000 and 1,500 pounds per square inch, the alloys, of course, are better. Figure 5 shows that in these tests at room temperature, F-3 alloy has bursting characteristics different from other alloys. It seems to retain its strength ratio to copper-lead equally at all stresses.

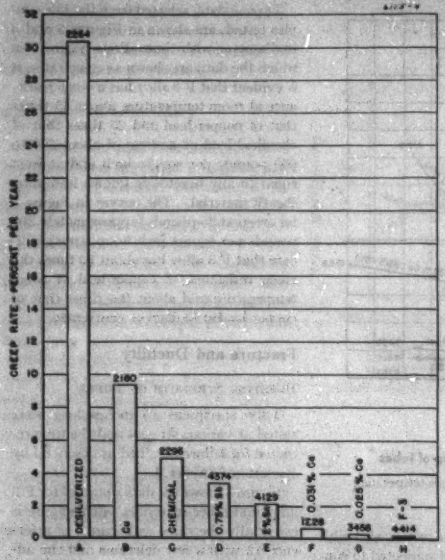


Figure 4. Creep rate of tubes

61-pound gauge, room temperature

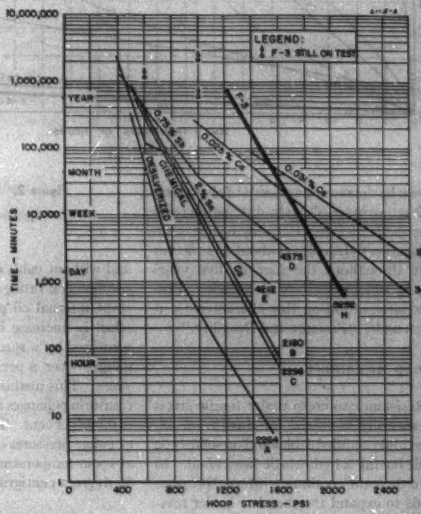


Figure 5. Bursting strength of tubes

Room temperature

This behavior leads to another point, that of the type or appearance of the failure. It has been observed that when lead fails under static long-time load at stresses up to approximately 30 per cent of ultimate strength (too low to cause appreciable plastic flow), the fractures are intercrystalline.[13,14,15] This type of failure is referred to as "stress cracking." The types of fracture produced by burst tests for commercial grades of lead and some alloys were described by Bassett and Snyder.

Figures 6, 7, and 8 show the type of failure obtained with F-3, calcium, and tin alloys. Other illustrations appear in reference 12.

No sample of F-3 alloy has failed in these bursting tests at stresses of 1,000 pounds per square inch or less, even though specimens have been on test for over four years. Specimens tested at 1,250 pounds per square inch have failed without stress cracking.

Data presented in Figure 9 indicate that F-3 alloy retains its good ductility in low-stress long-time tests as well as in short-time tests.

Bursting Strength of Long Lengths

Burst tests on long lengths (150 to 300 feet) of F-3 alloy pipe, each length comprising the total footage from one to three complete lead press charges, were conducted to locate the weakest part of the length. These samples were sealed on the ends with compression fittings and subjected to continuous 85-pound air pressure until failure. After the initial failure, ten feet of pipe from the finish of the charge was resealed on the ends and the test continued until final failure.

Table II summarizes the data thus obtained.

Table II. Bursting Strength of Full-Charge Lengths of Pipe

Approximately 850 Pounds Per Square Inch, Room Temperature

Material	Approximate Time to Failure, Months: Weakest Point of Full Length	Approximate Time to Failure, Months: Uniform 10 Feet at End of Charge	Location of Weakest Point of Full Length
Copper-lead	1	3	Charge weld
Tin alloy	1/2	3	Charge weld
Antimony alloy	1	9	Charge weld or where deformed by mechanical damage
Calcium alloy	1/2	24	Charge weld or where deformed by mechanical damage
F-3 alloy	13	No failure after four years	Adjacent to press-stop mark

Stress–Strain

Nonferrous metals including lead do not behave elastically; that is, they do not follow Hooke's law up to a certain stress point, the yield point. However, they do exhibit a certain degree of elasticity on short-duration tests. Elasticity, if present in a cable sheath, would be of some practical importance in producing some recovery in the radial expansion of the sheath after the initial high pressure developed during the start of a load cycle.

Test specimens 15 inches long like those used for burst tests were fitted with SR-4 strain gauges and subjected to repeated pressure cycles of successively increasing magnitude. The strain and recovery during each test cycle were noted and plotted in Figures 10 and 11. Each point on the curves represents about one minute elapsed time. The figures show that copper-lead undergoes rapid strain at stresses above about 500 pounds per square inch hoop

Figure 6. Burst failure of F-3 alloy

Ductile break (magnified four times), sample 5,252
1,250 pounds per square inch, 10,400 hours, 18.4 per cent expansion

stress, whereas F-3 alloy withstood about three times this stress to produce the same amount of permanent set.

Vibration Fatigue

Flattened-strip specimens were machined with reduced sections and carefully calibrated for stress calculations. These were flexed in a vibrating-reed Bell-Laboratories-type machine at 750 cycles per minute, the deflection being varied to obtain different stresses in duplicate specimens.

Figure 12 shows the data as stress versus number of cycles (S/N) curves. The resistance to vibration fatigue of F-3 alloy is much superior to that of copper-lead and also superior to that of antimony and tin alloys which have been used commonly for sheaths on overhead power cables.

Corrosion

Laboratory corrosion tests indicate that F-3 alloy has resistance to ground water and acidic fluids equivalent to that of most high-purity leads.[14] It has been observed that F-3 alloy sheaths are brighter and remain brighter in ordinary atmospheric exposure than copper-lead.

In general, it has been found that where corrosion is experienced, mitigating measures are required regardless of the chemical composition of the sheath.

Joint Sleeves

If the joints on impregnated-paper-insulated cable are completely filled with compound and sealed without any provision for thermal expansion, then internal pressures developed in the cable during load cycles will appear also in the joints. Joint sleeves are usually considerably larger in diameter than the cable sheaths, and hence for given internal pressures, the hoop

Figure 8. Burst failure of two per cent tin alloy

Intercrystalline break (magnified four times), sample 4,212
1,000 pounds per square inch, 216 hours, 1.8 per cent expansion

Figure 7 (above). Burst failure of 0.025 per cent calcium alloy

Intercrystalline break (magnified four times), sample 1,867
1,500 pounds per square inch, 292 hours, 1.7 per cent expansion

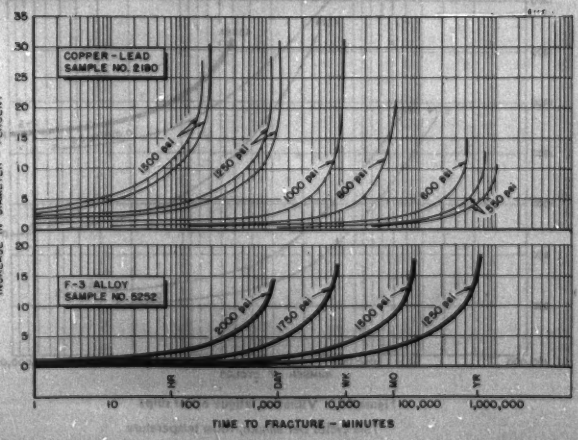


Figure 9. Ductility of tubes (room temperature)

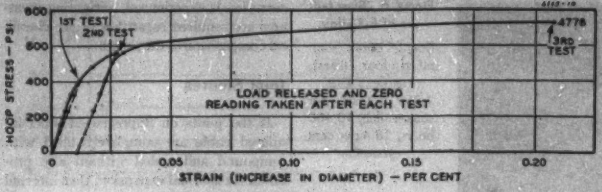


Figure 10. Stress-strain, copper-lead (tubes, room temperature)

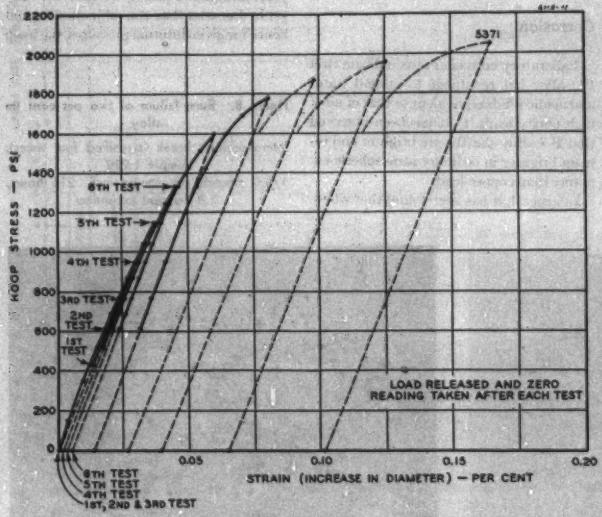


Figure 11. Stress-strain, F-3 alloy (tubes, room temperature)

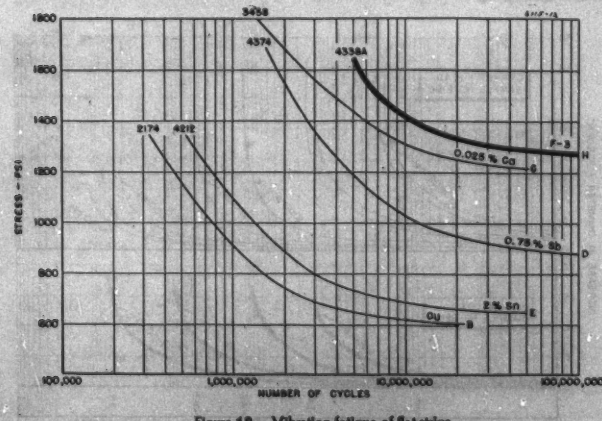


Figure 12. Vibration fatigue of flat strips
750 cycles per minute, room temperature

stresses in the sleeves are usually considerably greater than those in the sheaths unless the sleeves are made appreciably thicker.

With F-3 alloy for the cable sheath, having somewhat greater strength and considerably lower creep rate than lead sheaths, higher internal pressures can be expected in the sheaths and joint sleeves. It will become desirable, therefore, either to use material stronger than lead for the joint sleeves or to use some method of reinforcing the joint casing. Thus it may be quite desirable to have the joint sleeves made of F-3 alloy as well as the cable sheaths. Test joints have been made from extruded F-3 alloy sleeves and no difficulty was experienced in beating the ends or in wiping the joints.

Advantages of Improved Cable Sheathing

For some underground cables, the life in service is limited by the ability of the sheath to withstand repeated bending in the manholes caused by cable movement. In such cases the use of F-3 alloy will permit either higher loading for equal life of the cable or longer life with equal loading. For many installations, changes in the system or other factors make it more economical to obtain greater usage of the investment rather than to obtain much greater life.

The lower creep rate of the F-3 alloy will permit the use of higher internal pressures. This is especially beneficial on either oil-filled or gas-filled cables. A limiting hoop stress of 125 pounds per square inch has been established for design purposes for copper-bearing lead sheaths. This limitation restricts the internal pressures for oil-filled cables with standard sheath thicknesses to about 14-pound gauge for 2 1/2-inch cable or 12-pound for 3 1/2-inch cable. To withstand higher internal pressures, lead sheaths must be reenforced with layers of paper and copper tapes which require a costly double-sheath construction.

With F-3 alloy sheath, the equivalent stress for a similar creep rate is about 200 to 300 pounds per square inch based on data for tube specimens. If the limit is tentatively set at 200 pounds per square inch then with standard thicknesses the internal pressures can be increased safely to 22.5 pounds for 2 1/2-inch-thick cable or 19 pounds for 3 1/2-inch cable. By increasing the sheath thicknesses 40 or 50 mils, it becomes possible to use single sheaths on pressure-type cables with internal pressures of 25- or 30-pound gauge. This would avoid the use of double-sheath construc-

tion on, for example, some medium-pressure gas-filled cables.

Since cable sheathing must withstand the working and wear involved in installation which produce gouging and scoring of the outer surface, the thicknesses for most solid-type cables should not be reduced much from the present standard thicknesses. The sheath must be sufficiently thick to have long life in spite of such damages. The present standard thicknesses for lead have been evolved from long experience and are known to be adequate for normal conditions of use. At least until more experience is obtained in the use of F-3 alloy, the same thicknesses as for lead are recommended. For special conditions, where in the past extra-thick sheaths of ordinary lead have been required, the use of F-3 alloy will warrant a reduction.

Conclusions

1. A new cable sheath alloy of arsenical lead (F-3 alloy) has been produced. It has been successfully applied in manufacture to cable which has been installed in commercial lines.

2. F-3 alloy has been shown to have much better properties for power cable sheaths than any of the materials previously tried.

3. With this new type of sheath, the larger cables can carry higher loads without shortened life caused by cracking of the sheaths in daily bending in the manholes.

4. The limiting internal pressures will be appreciably higher than for lead sheaths, which may permit the use of single sheaths on some pressure-type cables where with lead the more costly double-sheath construction is required.

5. Since this alloy is harder than commercially pure lead, a reduction in troubles in service caused by mechanical damages can be expected.

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Electrical Accuracy of Selsyn Generator—Control Transformer System

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THE military requirements for high accuracy position control systems have placed emphasis on the need for a voltage signal source which can indicate electrically a mechanical shaft position. In addition this signal source must have high accuracy, marked dependability, and the capability of continuous mechanical rotation. A modification of the conventional Selsyn generator-motor system[1] has been developed and used extensively to fill this need.

This system,[2] shown schematically in Figure 1, consists of a generator in which a single phase a-c field is established with its space orientation determined by the position of the rotor, electrically connected to a control transformer in the rotor winding of which is induced a similar alternating voltage whose magnitude and polarity depend on the relative position of this rotor with respect to that of the generator. Ideally the control transformer rotor voltage versus the difference in the rotor angular position characteristic is a sinusoidal one, as is shown in Figure 2.

In effect, the presence of the single-phase magnetic field in the generator rotor induces voltages in the three stator windings of the generator. These voltages impressed on the three stator windings of the control transformer produce currents there which establish a single-phase magnetic field in the air gap of the same space position as that of the generator rotor. Depending on the actual orientation of the control transformer rotor with respect to the generator rotor, the voltage induced in the rotor winding may vary from a maximum of one polarity through zero to a maximum of the other polarity. If the control transformer rotor is positioned so as to maintain zero voltage across its terminals, it then maintains a fixed angular relationship to the generator rotor. Hence, it is possible to position the control transformer shaft properly with respect to the generator position by maintaining zero voltage on the control transformer terminals.

Although this system inherently has a high accuracy of the order of 0.3 degree, it is not completely error-free. To design Selsyn systems which are more accurate, it is necessary therefore to determine the effect of various factors which can contribute to electrical errors. The conditions under which errors are to be considered here are

1. Stationary orientation of both machines. This condition also explains the predominate error phenomenon from standstill up to speeds of three or four per cent of synchronous speed.

2. Constant velocity for both machines with a fixed angular separation between them. This condition considers the effect of "speed" voltages caused by rotation at speeds of from three or four per cent of synchronous speed on up to and above synchronous speed.

Conclusions

From calculations based on the analysis presented here, as well as other analyses, and from test measurements, the following conclusions are evident:

1. Static errors are of two general types, those which are predominately
(*a*) in time phase with the normal position error, or
(*b*) in time quadrature (out of phase) with the normal position error.

2. The in-phase errors are caused by unbalanced reactance either in the stator windings or the interconnecting lines or in the mutual reactance between rotor and stator of either machine. For this condition, zero magnitude control transformer voltage can be obtained, but not with the control transformer rotor 90 degrees from the generator rotor.

3. The out-of-phase errors are caused by unbalanced resistances in the stator windings or lines between generator and control transformer. For this condition there is no one control transformer rotor position where zero magnitude voltage is obtained.

4. Errors present at standstill are minimized by proper electrical design and care in manufacture. By judicious choice of the pitch, distribution, and skewing of windings and by properly shaping the pole face of the rotors, the fifth and seventh harmonics of mutual flux between rotor and stator of the two machines are eliminated and the in-phase errors thereby are reduced. Care in manufacturing insures that there is a minimum of phase unbalance of resistance or reactance, thus tending to eliminate the errors noted in items 2 and 3.

5. Constant velocity errors tend to be a combination of the in-phase and out-of-phase type. At low speeds the dominant effect is to shift the rotor position at which zero voltage is obtained, there still remaining a small out-of-phase component. At high speed the dominant effect is the introduction of an out-of-phase voltage, the so-called speed voltage.

6. The constant velocity errors are dependent on the ratio of the actual speed of rotation to the synchronous speed for the given excitation frequency. Hence, the use of higher excitation frequencies such as 400 cycles instead of 60 cycles would tend to minimize these effects.

Analysis

Accuracy at Standstill

The generator-control transformer system at standstill appears as three inductive coupled circuits as shown in Figure 3. The steady-state a-c equations of voltages for these circuits are

$$[r_{aa}+r_{ac}+j(X_{aa}+X_{ac})]i_a+[r_{abc}+r_{abc}+j(X_{abc}+X_{abc})]ib+jX_{MDaa}I_D=0 \quad (1)$$

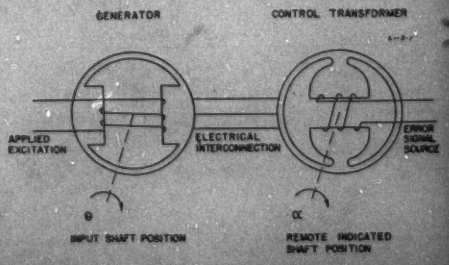

Figure 1. Schematic diagram of Selsyn generator-control transformer system

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The author wishes to thank T. C. Johnson, who suggested this investigation and assisted in obtaining the experimental measurements. Thanks also are due Miss Jane Crawford, who is responsible for determining many of the calculated curves.

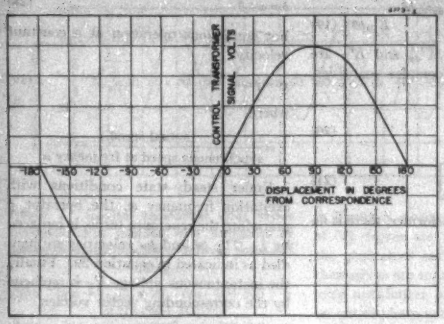


Figure 2. Ideal transformer voltage output versus angular displacement

$$[r_{abb}+r_{abc}+j(X_{abb}+X_{abc})]i_a+[r_{bb}+r_{bc}+j(X_{bb}+X_{bc})]ib+jX_{MDbb}I_D=0 \quad (2)$$

$$jX_{MDbb}i_a+jX_{MDbb}i_b+(R_D+jX_{Dd})I_D=E_d \quad (3)$$

The various symbols used are defined in the nomenclature and are consistent with the synchronous machine representation of Doherty and Nickle,[3] Prentice,[4] and Park.[5] It will be noted that the nomenclature provides direct relationships between line-to-line reactances, easily obtainable from test, and the direct and quadrature reactances, which are very convenient for analytical work and are used extensively in the references cited above.

The mutal reactances X_{Mbb} and X_{MDb} here considered include only the lower order harmonics, that is, up to the eleventh. Only odd harmonics are present because of the salient pole construction, and the third and ninth components are absent because of the 3-phase stator winding arrangement. Higher harmonics could well be included in a similar fashion. The control transformer is effectively a round-rotor machine and is represented as such.

From equations 1–3, the vector currents i_a and i_b which have a magnitude and time phase can be determined. The voltage which exists in the control transformer rotor is dependent on these currents and α, the angular position of the control transformer rotor. Thus,

$$E_c=jX_{Mc}[i_a\cos(\alpha+30)+i_b\cos(\alpha-30)] \quad (4)$$

The Selsyn control transformer indicating system depends on there being a fixed angular displacement between the generator rotor position, θ, and the control transformer position of zero voltage. This displacement is normally 90 degrees hence the position error e_p, can be defined as

$$e_p=\theta-(\alpha+90) \quad (5)$$

where θ is the independent variable used in equations 1–3 and α is calculated from the condition $E_c=0$ in equation 4.

Referring to equation 4, zero control transformer volts is obtained when

$$i_a\cos(\alpha+30)+i_b\cos(\alpha-30)=0 \quad (6)$$

Assuming that the currents i_a and i_b from equations 1–3 may not be in time phase, and taking the instant when i_a is zero as a time reference,

$$i_a=I_a\sin\omega t \quad (7)$$

$$i_b=I_b\sin(\omega t+\beta) \quad (8)$$

where I_a and I_b are the current magnitudes, and β is the phase angle between them.

Combining equation 6–8 and separating the resultant expression into sin ωt and cos ωt components,

$$\sin\omega t[I_a\cos(\alpha+30)+I_b\cos\beta\times\cos(\alpha-30)]+\cos\omega t[I_b\sin\beta\cos(\alpha-30)]=0 \quad (9)$$

For equation 9 to be equal to zero for all values of time, the coefficients of the sin ωt and cos ωt terms both must be zero, With $\beta=0$, the cost ωt coefficient goes to zero, and the coefficient of sin ωt gives the following defining condition for α at zero control transformer voltage:

$$\tan\alpha=-1.732\left(\frac{I_b+I_a}{I_b-I_a}\right) \quad (10)$$

Referring to equation 9 and noting that in the usual case the time phase difference β is small, one realizes that by positioning α in the location defined by equation 10, the sin ωt component of voltage is made zero.

Hence there remains only a cos ωt component of voltage which, since β is small, is also small.

For the case where $\beta\neq0$, the control

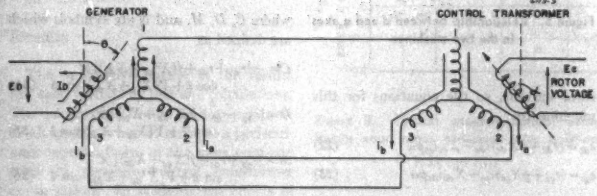


Figure 3. Elementary diagram of Selsyn generator-control system at standstill

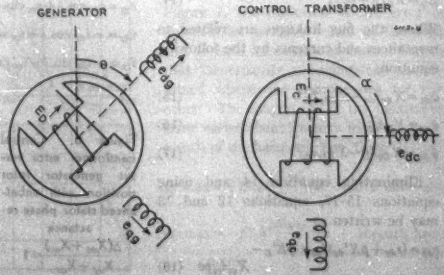


Figure 4. Two-reaction theory presentation of generator and control transformer

transformer error is then a voltage the magnitude of which is

$$e_{\epsilon\alpha} = I_b X_{M1\alpha} \sin\beta \cos(\alpha+30) \quad (11)$$

The foregoing analysis indicates the significant fact that there is a 90-degree difference in time phase of the errors $e_{\epsilon\beta}$, where the voltages are of sin ωt time phase, and the errors $e_{\epsilon\alpha}$, where the voltages are of cos ωt time phase.

Through use of the analytical means developed in the preceding analysis, the effects of phase unbalance in such machine parameters as reactance, resistance, and mutual coupling have been investigated.

Data for generator:

$r_{a_d} = 10$ ohms	$E_y = 115$ volts
$r_{a_y} = 5$ ohms	$\omega = 377$ radians per second
$r_{b_f} = 10$ ohms	
$R_D = 5$ ohms	$X_{M1y} = 0$ except as noted on curves
$X_{a_d} = 120.5$ ohms	
$X_{a_y} = 39.5$ ohms	$X_{M1y} = 0$ except as noted on curves
$X_{D_d} = 110$ ohms	
$X_{M1_d} = 95$ ohms	

Data for control transformer:

$r_{a_d} = 100$ ohms	$X_{d_c} = X_{q_c} = 1,200$ ohms
$r_{a_{hc}} = 50$ ohms	
$r_{b_c} = 100$ ohms	$X_{M1_c} = 1,000$ ohms

Accuracy Under Constant Velocity Operation

In the treatment of the generator-control transformer system for this condition, it is premised that both machines have balanced windings. The effect of resistance or reactance phase unbalance is not considered, and only the fundamental component of mutual reactance between rotor and stator winding is included.

The following equations may be written for the generator machine in Figure 4, where the direct and quadrature axis voltage equations include transformer and speed voltage effects in the manner of Park.[5]

$$e_{a_d} = r_{a_d} i_{a_d} + p\psi_{a_d} - \psi_{a_q} p\theta \quad (12)$$

$$e_{a_y} = r_{a_y} i_{a_y} + p\psi_{a_y} + \psi_{a_d} p\theta \quad (13)$$

$$E_D = R_D I_D + p\psi_{D_d} \quad (14)$$

Where the flux linkages are related to reactances and currents by the following equations

$$\psi_{a_d} = X_{a_d} i_{a_d} - X_{M1_d} I_D \quad (15)$$

$$\psi_{a_y} = X_{a_y} i_{a_y} \quad (16)$$

$$\psi_{D_d} = X_{D_d} I_D - X_{M1_d} i_{a_d} \quad (17)$$

Eliminating equation 14 and using equations 15–17, equations 12 and 13 may be written as

$$e_{a_d} = (r_{a_d} + pX'_{a_d}) i_{a_d} - pE'_D - X_{a_y} i_{a_y} p\theta \quad (18)$$

$$e_{a_y} = (r_{a_y} + pX_{a_y}) i_{a_y} + X'_{a_d} i_{a_d} p\theta - E'_D p\theta \quad (19)$$

Where the symbols X'_{a_d} and E'_D are abbreviations of more complex quantities, namely,

$$X'_{a_d} = X_{a_d} - \frac{pX^2_{M1_d}}{R_D + pX_{D_d}} \quad (20)$$

$$E'_D = \frac{X_{M1_d}}{\omega}\left[\frac{E_D}{R_D + pX_{D_d}}\right] \quad (21)$$

For the control transformer, there is no

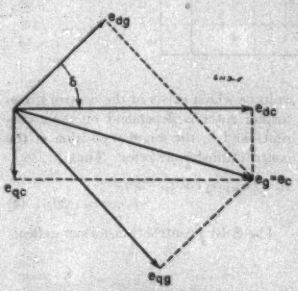


Figure 5. Relationship between d and q axes in the two machines

rotor current, so the equations for this machine are

$$e_{a_c} = (r_{a_c} + pX_{a_c}) i_{a_c} - X_{q_c} i_{q_c} p\alpha \quad (22)$$

$$e_{q_c} = (r_{q_c} + pX_{q_c}) i_{q_c} + X_{a_c} i_{a_c} p\alpha \quad (23)$$

In terms of the actual phase voltages, the terminal conditions for generator and control transformer are the same. The phase currents for generator and control transformer, however, are opposite in sign. From these relationships, one can relate the direct and quadrature components of voltages and currents for the generator in terms of the control transformer.

$$e_{a_d} = e_{a_c} \cos\delta - e_{q_c} \sin\delta \quad (24)$$

$$e_{a_y} = e_{a_c} \sin\delta + e_{q_c} \cos\delta \quad (25)$$

$$i_{a_d} = -i_{a_c} \cos\delta + i_{q_c} \sin\delta \quad (26)$$

$$i_{a_y} = -i_{a_c} \sin\delta - i_{q_c} \cos\delta \quad (27)$$

$$\delta = \alpha - \theta \quad (28)$$

For continuous operation at a constant velocity,

$$p\theta = p\alpha = V\omega \quad (29)$$

where

$$V = \frac{\text{actual speed}}{\text{synchronous speed at frequency } \omega}$$

Under steady-state conditions with excitation frequency ω, the operator p preceding the reactance terms is replaced by j. The $p\theta$ and $p\alpha$ velocities are handled as indicated in equation 29. Finally the instantaneous voltage E_D is replaced by the corresponding vector voltage,

$$E_D = \sqrt{2} E_y \sin\omega t = E_y \underline{|0} \quad (30)$$

In vector terms, E'_D is equivalent to

$$E'_D = \frac{X_{M1_d}}{\omega}\left[\frac{E_y \underline{|0}}{R_D + jX_{D_d}}\right] \quad (31)$$

Combining the preceding equations and simplifying the results yield the following two expressions:

$$Ci_{a_c} + Di_{q_c} = j\omega E'_D \quad (32)$$

$$Mi_{a_c} + Ni_{q_c} = +V\omega E'_D \quad (33)$$

where C, D, M, and N are symbols which are defined as

$$C = -[r_{a_d} + r_{a_c} + j(X'_{a_d} + X_{a_c})] \times \cos\delta + V(X_{a_y} + X_{a_c}) \sin\delta \quad (34)$$

$$D = [r_{a_d} + r_{q_c} + j(X'_{a_d} + X_{q_c})] \times \sin\delta + V(X_{a_y} + X_{q_c}) \cos\delta \quad (35)$$

$$M = [r_{a_y} + r_{a_c} + j(X_{a_y} + X_{a_c})] \times \sin\delta + V[X'_{a_d} + X_{a_c}] \cos\delta \quad (36)$$

$$N = [r_{a_y} + r_{q_c} + j(X_{a_y} + X_{q_c})] \times \cos\delta - V[X'_{a_d} - X_{q_c}] \sin\delta \quad (37)$$

From equations 32 and 33

$$i_{a_c} = \frac{Nj\omega E'_D - DV\omega E'_D}{CN - DM} \quad (38)$$

and the actual control transformer output voltage is

$$E_c = -jX_{M1_c} i_{a_c} \quad (39)$$

Calculations were made using equations 31–39 for speeds ranging from 0 to synchronous speed, using the following data:

Generator:

$r_{a_d} = r_{a_y} = 29.7$ ohms $\quad X_{D_d} = 208$ ohms

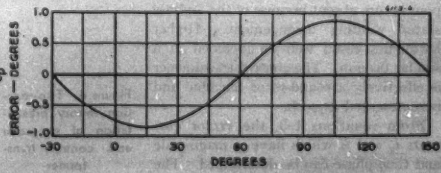


Figure 6. Control transformer error versus generator rotor position with unbalanced stator phase reactance

$$\frac{\Delta(X_{a_d} + X_{a_c})}{X_{a_d} + X_{a_c}} = 1$$

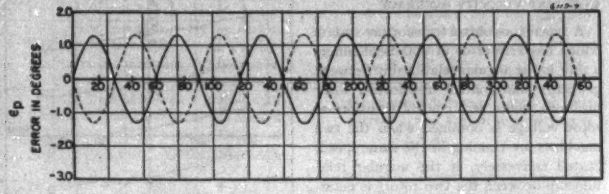


Figure 7. Control transformer error versus generator rotor position with harmonics of generator mutual reactance between rotor and stator

Solid line—$X_{M\,Dag} = 95 \cos (\theta+30) + 2 \cos (5\theta+30)$

Broken line—$X_{M\,Dag} = 95 \cos (\theta+30) + 2 \cos (7\theta+30)$

$X_{dg} = 230$ ohms
$X_{M1g} = 204$ ohms
$X_{qg} = 62$ ohms
$R_D = 12.7$ ohms
$|E_g| = 115$ volts
$\omega = 377$ radians per second
$V = 0\text{–}1.0$

Control transformer:

$r_{dc} = r_{qc} = 686$ ohms
$X_{dc} = X_{qc} = 3{,}320$ ohms
$X_{M1c} = 1{,}860$ ohms

Results

The qualitative nature of the results has been verified by test and calculations. The quantitative results are not applicable to all machines but do indicate a performance representative of the more common type of generator-control transformer combination. In studying the effects of resistance and reactance unbalances, the magnitude of the quantities were chosen arbitrarily and do not reflect the usual values of machine constants.

The accuracy of Selsyn systems in use at present is remarkably high. As shown in Figure 8, position errors not in excess of 0.2 degree are obtainable. Although the generators and control transformers themselves are manufactured with resistance unbalances of less than ten ohms, an out-of-phase voltage of 0.25 volt, such as shown in Figure 9, may be obtained when these machines are used in system including switches.

Although the results are discussed in two separate sections, namely static accuracy and constant velocity accuracy, it should be noted that in actual operation errors due to both unbalance and velocity exist simultaneously and may combine in a number of ways to make up the total error. Hence, comparisons with test measurements under dynamic conditions tend to be difficult to analyze.

Static Accuracy

Since the impedance of the generator and control transformer is largely reactive, it follows that an unbalance in the phase values of reactance of either machine causes the in-phase current magnitudes to be altered from the values necessary for errorless operation. This shifts the flux orientation in the control transformer and requires that the rotor be moved slightly from its position of correspondence with the generator.

Specifically, unbalance in the stator phase values of reactance produces a space error which varies with the second harmonic of the generator rotor orientation (Figure 6). The maximum value of error for values of unbalance reactance up to about ten per cent is given by the expression

$$\epsilon\phi \text{ max} = 8° \frac{\Delta(X_{aa}+X_{ac})}{X_{aa}+X_{ac}}$$

This relationship applies for machine constants given in the data in the section on static accuracy.

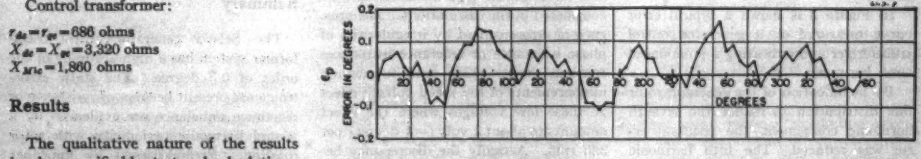


Figure 8. Typical generator-control transformer error versus generator rotor position

From test data

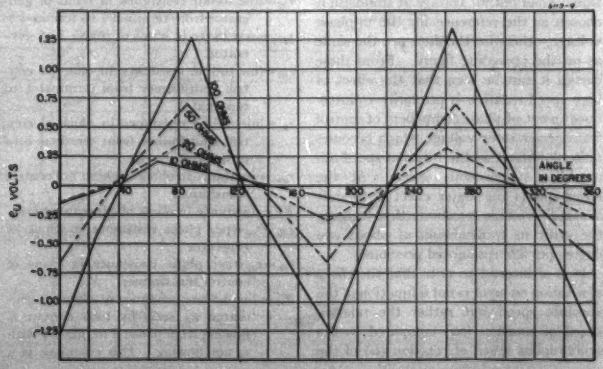


Figure 9. Control-transformer quadrature error voltage as a function of generator rotor angle

For various amounts of added resistance in one stator line

Points of maximum, minimum, and zero values of voltage are joined by straight lines

The presence of fifth and seventh harmonics in the mutual flux between rotor and stator of either machine is evidenced by the occurrence of a space error which varies as the sixth harmonic of the generator rotor orientation. As shown in Figure 7, the direction of the error is opposite for positive values of the fifth and seventh harmonics of mutual flux so that theoretically a balance can be obtained where one compensates for the other. The magnitude of the maximum error varies about linearly with the magnitude of the harmonic flux, thus

$$\epsilon\phi \text{ max} = +57.3° \frac{X_{M5g}}{X_{M1g}} \text{ for } + \text{ fifth harmonic}$$

$$\epsilon\phi \text{ max} = -57.3° \frac{X_{M7g}}{X_{M1g}} \text{ for } + \text{ seventh harmonic}$$

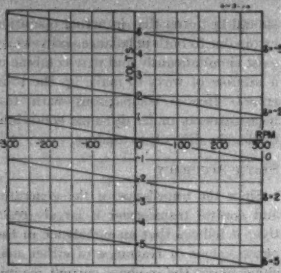


Figure 10. Calculated values of control transformer voltage (in phase component) versus speed

For generator-control transformer with fixed angular separation (δ)

Figure 7 verifies these approximate relations for the case of a machine with constants as given in the section on static accuracy.

In Figure 8 is shown a typical error curve measured on a generator-control transformer and indicating a pronounced sixth harmonic.

By modification of the generator rotor flux distribution to reduce the seventh harmonic component, the resultant error was reduced. The fifth harmonic of flux is absent from this type machine because of the stator slot winding arrangement.

The presence of unequal values of resistance in the different stator phases causes a shift in the time phase of the stator currents. The current magnitudes which are determined primarily by the phase reactances are relatively unchanged. Under this condition there is no control transformer rotor position where zero voltage exists at all instants of time. At zero ϵp error position, there exists a voltage induced in the control transformer rotor which is in time quadrature with the normal position error voltage. Turning the control transformer rotor from the zero space error position merely brings the voltage in phase with the normal signal voltage and greatly increases its magnitude. The polarity of the voltage depends on the direction in which the rotor is moved. The magnitude of the time quadrature component of voltage is about linearly proportional to the amount of unbalanced resistance as shown in Figure 9. This curve, obtained experimentally, verifies calculations which indicate a second harmonic variation of control transformer rotor minimum voltage as a function of generator rotor position.

Constant Velocity Accuracy

A generator-control transformer system which has zero error at standstill suffers a shift in the angular relationship between generator and control transformer rotor positions where zero control transformer rotor voltage is obtained when the two machines are running at the same speed. Stated conversely, if the angular relationship between the two rotors is maintained fixed and the two rotors are run at a number of constant speeds, the control transformer rotor voltage changes magnitude as a function of speed, the frequency of the output voltage being maintained constant throughout. Figure 10 shows the calculated values for the in-time-phase component of rotor voltage as a function of speed for a number of fixed values of relative rotor displacement. These curves compare fairly well with the experimentally measured curves shown on Figure 11, which show the smoothed "average" voltage-speed effect for the same type machines as were considered in the calculations. The presence of errors caused by irregularities of phase resistance or reactance introduces spurious errors which tend to obscure measurements of the speed voltage effect at these low voltages where the effect amounts to about 1 volt (=1 degree) per 320 rpm. Actually the discrepancy between calculations and test is well within the limit of experimental accuracy.

In Figure 12 is shown the in-phase and out-of-phase components of control transformer rotor voltage as a function of speed up to synchronous speed for a number of fixed values of angular separation. The applied voltage to the generator rotor is taken as the in-phase voltage reference. A time phase shift of about 15 degrees at 60 cycles per second takes place in this generator-control transformer system at standstill. In Figure 13 the control transformer output voltage at standstill is chosen as the reference for the in-phase voltage, otherwise the data are the same as on the preceding figure. From these curves it can be seen that the effect of high speed rotation is primarily to introduce an out-of-phase component of control transformer rotor voltage which becomes quite dominant as the rotation speed approaches synchronous speed. At the lower speeds the major effect is to shift the zero voltage position, thus causing the error in transmission of about one degree per 320 rpm noted previously.

It is of interest to note that the effect of rotation on error is not a function of the absolute speed but rather the relative speed of rotation ($n\omega$) compared to the synchronous speed of rotation (ω) of the excitation frequency. Thus by doubling the excitation frequency, an error of one degree would be obtained at about 640 rpm instead of 320.

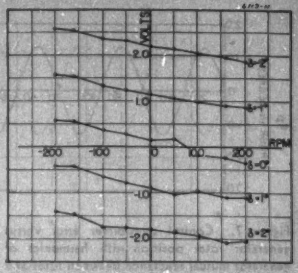


Figure 11. Averaged measured values of control transformer voltage versus speed

From test data. For generator-control transformer with fixed angular separation (δ)

Summary

The Selsyn generator-control transformer system has a high accuracy of the order of 0.3 degree. The static errors which are present because of resistance or reactance unbalance are evidenced by a second harmonic periodicity with rotor rotation. Errors caused by improper shaping of the rotor appear as higher harmonics of rotor position such as the sixth.

Even though a generator-control transformer system has no static errors, speed voltage effects produce a dynamic error which is of the order of one degree per 320 rpm for present-day 60-cycle machines.

Nomenclature

r_{ag} = line-to-line resistance in ohms of generator from terminal 1 to terminal 2

r_{bg} = line-to-line resistance in ohms of generator from terminal 1 to terminal 3

r_{abg} = resistance in ohms of phase 1 of generator

r_{ac} = line-to-line resistance in ohms of control transformer from terminal 1 to terminal 2

r_{bc} = line-to-line resistance in ohms of control transformer from terminal 1 to terminal 3

r_{abc} = resistance in ohms of phase 1 of control transformer

R_D = resistance in ohms of generator rotor

$r_{dg} = r_{qg}$ = per phase resistance in ohms of generator

$r_{dc} = r_{qc}$ = per phase resistance in ohms of control transformer

X_{ag} = line-to-line reactance in ohms of generator as seen by loop current i_a flowing from phase 2 to phase 1 with i_b not flowing. This reactance is a

second harmonic function of generator rotor position. Its numerical value may be obtained from a measurement of maximum and minimum values of the line-to-line reactance as viewed from terminals 1 and 2, with terminal 3 not connected. Expressed in terms of the per phase values of direct and quadrature axis reactances,

$X_{aq} = X_{dq} + X_{qq} - (X_{dq} - X_{qq}) \times \cos(2\theta - 120)$

X_{bq} = line-to-line reactance in ohms of generator as seen by loop current i_b flowing from phase 3 to phase 1. This reactance is a second harmonic function of generator rotor position, and its value may be obtained from a measurement of maximum and minimum values of line-to-line reactance as viewed from terminals 1 and 3.

$X_{bq} = X_{dq} + X_{qq} - (X_{dq} - X_{qq}) \times \cos(2\theta + 120)$

X_{abq} = mutual reactance in ohms of generator between circuit of loop current i_a and that of loop current i_b. Expressed in terms of the values of direct and quadrature reactances noted above,

$$X_{abq} = \frac{X_{dq} + X_{qq}}{2} - \frac{(X_{dq} - X_{qq})}{2} \times \cos[2\theta - 120]$$

X_{ac} = line-to-line reactance in ohms of control transformer as seen by loop current i_a flowing from phase 1 to phase 2 with i_b not flowing. Because of the absence of reactance variation with a change in control transformer rotor position,

$X_{ac} = X_{dc} + X_{qc}$

X_{bc} = line-to-line reactance in ohms of control transformer as seen by loop current i_b flowing from phase 1 to phase 3 with i_a not flowing

$X_{bc} = X_{ac} = X_{dc} + X_{qc}$

X_{abc} = mutual reactance in ohms of control transformer between circuit of loop current i_a and that of loop current i_b

$$X_{abc} = \frac{X_{dc} + X_{qc}}{2}$$

X_{Dq} = reactance in ohms of generator rotor

X_{MDaq} = mutual reactance between generator stator windings, phases 1 and 2 and the generator rotor winding. This reactance is a function of the odd harmonics of rotor position; however, because of the 3-phase arrangement of the stator windings, those harmonics which are multiples of three are missing. Expressed in terms of the maximum values of the fundamental, X_{M1q}, fifth, X_{M5q}, and seventh, X_{M7q}, harmonics of generator mutual reactances between the rotor and the line-to-line stator windings,

$X_{MDaq} = X_{M1q} \cos(\theta + 30) + X_{M5q} \times \cos(5\theta - 30) + X_{M7q} \cos(7\theta + 30)$

X_{MDbq} = mutual reactance between generator stator windings phases 1 and 3 and the generator rotor windings. It is an odd harmonic function of generator rotor position as X_{MDaq}. Expressed in terms of X_{M1q}, X_{M5q}, and X_{M7q},

$X_{MDbq} = X_{M1q} \cos(\theta - 30) + X_{M5q} \times \cos(5\theta + 30) + X_{M7q} \cos(7\theta - 30)$

X_{M1q} = maximum value in ohms of fundamental of mutual reactance between generator rotor and stator windings, line-to-line

X_{M5q} = maximum value in ohms of fifth harmonic of mutual reactance between generator rotor and stator windings, line-to-line

X_{M7q} = maximum value in ohms of seventh harmonic of mutual reactance between generator rotor and stator windings, line-to-line

X_{M1c} = maximum value of mutual reactance in ohms of control transformer between line-to-line of stator and rotor winding

X_{dq} = per phase value of direct axis reactance in ohms of generator stator windings. In terms of the maximum value of X_{aq},

$$X_{dq} = \frac{X_{aq}}{2} \text{ (maximum)}$$

X'_{dq} = symbol used to represent the apparent reactance of the stator direct axis as modified by the presence of the current flowing in the rotor

X_{qq} = per phase value of quadrature axis reactance in ohms of generator stator windings. In terms of the minimum value of X_{aq},

$$X_{qq} = \frac{X_{aq}}{2} \text{ (minimum)}$$

X_{dc} = per phase value of direct axis reactance in ohms of control-transformer stator windings. In terms of X_{ac},

$$X_{dc} = \frac{X_{ac}}{2}$$

X_{qc} = per phase value of quadrature axis reactance in ohms of control-transformer stator windings. In terms of X_{ac},

$$X_{qc} = \frac{X_{ac}}{2}$$

$\Delta(X_{aq} + X_{ac})$ = ohms value of unbalance in

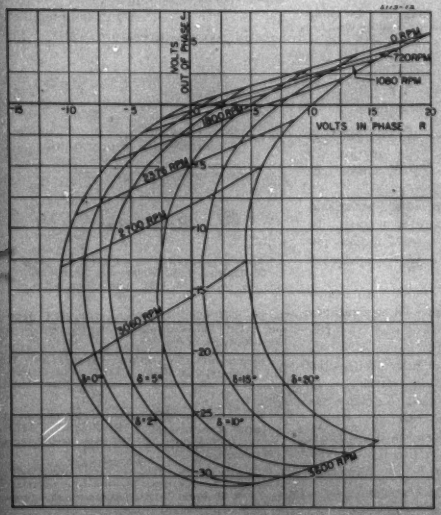
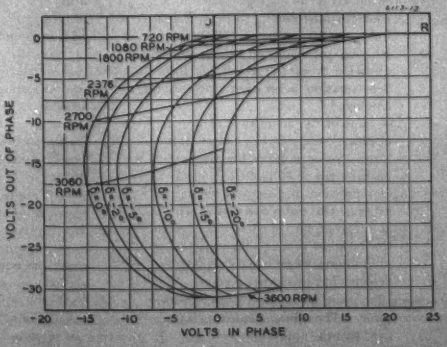


Figure 12 (left). Control transformer voltage components for constant velocity operation with fixed separation between rotors

Generator excitation voltage used as in-phase reference (R)

Figure 13 (below). Control transformer voltage components for constant velocity operation with fixed separation between rotors

Control transformer voltage at standstill is in-phase reference



loop reactance used for specifying error voltage e_ρ as a function of reactance unbalance

i_a, i_b = loop currents in amperes flowing in generator-control transformer stator circuits as shown in Figure 3

I_D = generator rotor current in amperes flowing as shown in Figure 3

I_a = rms value of the magnitude of the loop current i_a

I_b = rms value of the magnitude of the loop current i_b

i_{dg} = direct axis current in amperes flowing in generator stator circuit shown in Figure 4

i_{qg} = quadrature axis current in amperes flowing in generator stator circuit shown in Figure 4

i_{dc} = direct axis current in amperes flowing in control-transformer stator circuit shown in Figure 4

i_{qc} = quadrature axis current in amperes flowing in control-transformer stator circuit shown in Figure 4

ψ_{dg} = direct axis flux linkages in the generator stator

ψ_{qg} = quadrature axis flux linkages in the generator stator

ψ_{Dg} = direct axis flux linkages in the generator rotor

E_g = rms value of the magnitude of the excitation voltage impressed on the generator rotor

E_c = rms value of the voltage present at the rotor of the control transformer. This is the so-called control transformer signal voltage

E_D = excitation voltage applied to generator rotor

E'_D = symbol used to represent the voltage present in the stator of the generator produced by the actual excitation voltage in the generator rotor

e_{dg} = per phase value of direct axis voltage in volts for generator stator

e_{qg} = per phase value of quadrature axis voltage in volts for generator stator

e_{dc} = per phase value of direct axis voltage in volts for control transformer stator

e_{qc} = per phase value of quadrature axis voltage in volts for control transformer stator

$e\rho$ = position error in degrees between the control-transformer rotor position for zero volts output and the position 90 degrees displaced in a lagging direction from the generator rotor. See equation 5 for sign convention employed

e_R = rms value of the magnitude of the out-of-phase component of control transformer rotor voltage for that rotor position where $e\rho$ is zero

θ = angular position of generator rotor. In general, the units associated with θ are degrees, but in those cases where the term $p\theta$ is used, the units of θ are radians, so $p\theta$ equals an angular velocity in radians per second

α = angular position of control-transformer rotor. The same comments in regard to units apply to α as to θ

High Voltage D-C Testing of Rubber-Insulated Wire

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AT DIFFERENT STAGES in the manufacture of insulated wire and cable, various electrical and physical tests are made to ensure the quality and serviceability of the completed cable. One of the most important of these tests is the high voltage test, a-c or d-c. It may be applied to short sections of the insulated conductor as it passes through electrodes of various types, dry or wet, or to full factory lengths of the insulated wire, dry or wet.

The scope of this paper is limited to the results of an experimental study made on the voltage limits suitable for the high voltage d-c testing of factory lengths of plain insulated wire immersed in water. In addition to many sample tests, the study included tests on more than 5,500 different factory lengths of submarine cable conductor, insulated with natural rubber, synthetic rubber, or polyethylene. Such factors as testing voltage, type of fault, and immersion time were varied over a wide range. From these data test voltage limits are suggested; the lowest test voltage that will indicate serious defects and the highest test voltage that can be used without causing damage to sound insulation, from either the d-c test voltage itself or from impulse voltages incidental to the testing.

In the following discussion all insulating compounds are of the submarine type, all wire sizes are American Wire Gauge and all voltages are given as volts per mil thickness of insulation (total voltage per mils thickness). All alternating voltages are root-mean-square. Unless otherwise indicated, all d-c tests were made with negative polarity on the conductor.

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Dielectric Strength of Rubber and Polyethylene Insulated Wire

Knowledge of the d-c and impulse dielectric strength is essential to the proper selection of a suitable d-c test voltage. In Table I are given typical values for the dielectric strength of the materials covered in this discussion. They represent many tests made over several years time. All test specimens were five feet active length tested after 24 hours immersion in room temperature water. The

β = phase angle in degrees between the loop currents i_a and i_b. See equations (7) and (8) for the sign convention employed

ω = angular frequency in radians per second of generator excitation voltage. In the calculations, $\omega = 377$ radians per second corresponding to 60 cycles per second

V = speed of generator and control transformer rotors expressed as a ratio to synchronous speed at excitation frequency ω

$\delta = \alpha - \theta$ = difference in angular position between generator and control

C, D, M, N = symbols used to replace the more complicated reactance expressions of equations 34-37. These are of use only in literal work and need not appear in the numerical calculations

t = time in seconds

$p = \frac{d}{dt}$ = derivative with respect to time

j = operator indicating $\sqrt{-1}$

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calculated impulse wave was 1.5x40 microseconds. The d-c tests were made with a voltage increase of 700 volts per second. The alternating voltage was increased 500 volts per second. The wire size varied over a moderate range in the neighborhood of number 12 6/64 inch thickness.

Damage to Sound Insulation by Excessive Test Voltage

The tests reported in Tables II and III were made to investigate the possibility that the application of high d-c test voltage might damage sound insulation by causing a permanent decrease in the dielectric strength.

The tests in Table II were made on insulated wire samples of five feet active length after 24 to 48 hours immersion in room temperature water. All samples of the same size were cut from the same length and grouped in such a way as to minimize the effect of variation of dielectric strength along the length. After a 30-minute application of the direct voltages indicated in the table the samples were tested for a-c dielectric strength with a voltage increase of 500 volts per second. In all cases the a-c tests were made the day after the d-c tests, without removing the samples from the water.

The tests in Table III were made on number 12 solid, 6/64 inch thickness of natural rubber. A 175-foot length in water was tested at 640 volts d-c per mil for five minutes without failure and then cut into samples of 5-foot active length for the tests indicated in the table. The dielectric strength tests were made with a direct voltage increase of 700 volts per second and an impulse wave of 1.5x40 microseconds. There were five samples in each of the four groups. In other respects the testing conditions were similar to those of Table II.

Table I. Dielectric Strength of Rubber and Polyethylene Insulated Wire

Type of Insulation	Impulse Strength in Volts Per Mil	D-C Strength in Volts Per Mil	A-C Strength in Volts Per Mil
Natural rubber	1,070	1,500	350
GR-S rubber	1,030	1,400	370
Polyethylene	1,500	3,000	350

The results in Tables II and III show no real decrease in a-c or d-c strength resulting from previous applications of direct or impulse voltage. None of the variations apparent in the tables exceeds those usually found in such a collection of dielectric strength data. Therefore, the use of d-c testing voltages as high as one half of the 5-foot d-c dielectric strength in Table I should not result in any appreciable decrease in the dielectric strength of sound insulation.

Table II. Effect of High Voltage D-C Tests on Subsequent A-C Strength

Size	Previous Test	Number of Samples	60-Cycle Breakdown Voltage: Highest Volts Per Mil	Lowest Volts Per Mil	Average Volts Per Mil	Average in Per Cent of No D-C Test
Number 12 (7 strands)—$^{3}/_{64}$ inch thickness polyethylene	None	15	361	278	326	100
	800 volts per mil d-c	5	350	317	338	104
	1,600 volts per mil d-c	10	333	266	301	93
Number 6 (7 strands)—$^{3}/_{64}$ inch thickness GR-S rubber	None	15	350	293	319	100
	500 volts per mil d-c	5	363	286	313	98
	800 volts per mil d-c	10	388	300	334	105
Number 12 solid—$^{6}/_{64}$ inch thickness natural rubber	None	13	455	344	411	100
	500 volts per mil d-c	5	419	328	374	91
	800 volts per mil d-c	8	415	338	378	92
Number 6 (7 strands)—$^{6}/_{64}$ inch thickness natural rubber	None	5	445	361	422	100
	800 volts per mil d-c	5	470	378	440	104

Relation Between Type of Fault and Necessary Test Voltage

The object of high voltage testing is to indicate weak spots or partial faults in the insulation by applying enough voltage to cause the complete failure of such spots. Therefore, it is desirable to know something of the relation between the type of the partial faults and the test voltage necessary to develop such spots into complete failure.

In Table IV are given the results of voltage tests made on artificial faults in number 12 standard, 6/64 inch thickness natural rubber. After tying the wire to a wooden splint each fault was made by forcing a needle or revolving drill through the insulation to the conductor as indicated by completion of a buzzer circuit, then withdrawing the needle or drill. These faults were tested with high direct voltage after immersion in water for three days. The results in Table IV indicate that such faults may withstand direct voltage as high as 225 volts per mil of insulation for 40 minutes (20 minutes each polarity) without failure. Thus, a test voltage as low as this may not indicate faults that extend entirely through the insulation thickness. Open artificial faults were made in the same size wire by cutting away part of the insulation thickness at one spot. High voltage d-c tests on these faults indicated that a remaining thickness of 3/64 inch, or only one half the total thickness, is enough to withstand 500 volts d-c per mil of the total thickness without failure. A similar relation also is indicated by comparison of the test voltage with the dielectric strength values in Table I. For instance, a test voltage of 500 volts d-c per mil is only one third the d-c dielectric strength of natural rubber. Thus, a small part of the insulation at a single spot might withstand a test voltage of 500 volts per mil total thickness.

When rubber insulated wire is wound on a reel there may be considerable pressure between adjacent turns of wire. The results in Table V show the effect of such pressure on the d-c dielectric strength of artificial faults in wire, number 12, 6/64 inch thickness natural rubber. The d-c strength of needle faults in water was increased from 150 to 690 volts per mil, by applying pressure from adjacent rubber insulated wire as on a reel.

Also in Table V are the results of similar tests on a fault in the same size wire consisting of a *U*-shaped knife cut all the way to the conductor. After immersion in water for 24 hours under pressure from adjacent rubber insulated wire this fault had a d-c strength of 600 volts per mil and after the first failure a voltage of 480 volts per mil was necessary to cause a second failure.

Table III. Effect of High Voltage D-C and Impulse Tests on Subsequent D-C Strength

Previous Test	D-C Dielectric Strength Volts Per Mil: Highest	Lowest	Average
a—None	1,450	1,290	1,360
b—640 volts per mil d-c for 30 minutes	1,500	1,120	1,340
c—640 volts per mil d-c for 5 minutes, 6 times	1,480	1,310	1,360
d—850 volts per mil impulse, 6 times	1,530	1,380	1,470

In addition to these data on artificial faults two examples of natural faults are offered:

1. Three thousand feet of number 14 solid 3/64 inch thickness of natural rubber withstood, without failure, three voltage tests

five minutes each at 340 volts d-c per mil during a 12-day water immersion. After six months' additional room temperature immersion the wire had an insulation resistance of less than 10 megohms per 1,000 feet at 500 volts d-c because of two air pockets in the insulation so large that only ten per cent of the wall remained in a sound condition.

2. Ten thousand feet of number 12 standard, 6/64 inch thickness GR-S rubber withstood, without failure, three voltage tests five minutes each at 570 volts d-c per mil during a 12-day immersion. Subsequent immersion and high voltage testing finally disclosed an iron chip so located within the insulation that only one third of the thickness was left effective.

These data on both artificial and natural faults indicate that under some circumstances it is possible for serious faults to withstand several applications of d-c testing voltage as high as 500 volts per mil without failure.

Damage to Sound Insulation by Impulse Voltages Incidental to High Voltage D-C Testing

When factory lengths of insulated wire are at the d-c test voltage, abrupt grounding of the conductor is likely to produce momentary voltages that are higher than the test voltage. If these voltages exceed the impulse strength of the insulation, failures will ensue. There are three principal ways in which the conductor may be grounded abruptly:

1. Accidental flashover during test.
2. Intentional grounding after completion of test.
3. Failure of insulation on test.

The first way can be prevented by care and the second by the use of series resistance but limitation of the test voltage is the only known method of preventing damage from the third cause.

In a total of more than 17,000 voltage tests on more than 5,500 factory lengths with an insulation thickness in the general neighborhood of 6/64 inch and with different test voltages between 300 and 620 volts per mil on rubber and between 500 and 1,000 volts per mil on polyethylene, impulse failures have been limited to test voltages of 580 volts per mil and higher on natural or synthetic rubber and to 850 volts per mil and higher on polyethylene.

Investigation of these impulse voltages with cathode-ray oscillograph at direct voltages less than 100 volts indicates that such voltages may get as high as 1.8 of the applied voltage (test voltage). Application of this ratio to the impulse strengths in Table I gives minimum test voltages of 593, 573, and 835 volt per mil for natural rubber, GR-S rubber, and polyethylene respectively, at which impulse failures might be expected. These indications admittedly are not conclusive because of the low test voltage but it is interesting to note the close agreement with the testing experience reported in the preceding paragraph.

Conclusions

High voltage d-c testing has been found of considerable value in controlling the quality of insulated wire but no implication is intended in this paper that such testing is essential to the maintenance of satisfactory quality. Comparison of high voltage d-c testing of factory lengths with other kinds of testing is outside the paper's limited scope. If high voltage d-c tests are made on factory lengths it would be well to consider the following voltage limitations that have been indicated by experimental study to date.

If the d-c test voltage used on factory lengths is too high there is a possibility of developing enough impulse voltage to cause failures in sound insulation.

As a value for the highest d-c test voltage at which there is no danger from impulses one of the following is suggested:

1. Fifty per cent of the 5-foot impulse strength.
2. Five hundred volts per mil on rubber and 750 volts per mil on polyethylene if the impulse strength is not known.

Prolonged or repeated applications of d-c test voltage as high as 50 per cent of the 5-foot d-c strength do not cause any reduction in the dielectric strength of sound insulation. This value is above the maximum limitation in test voltage imposed by the impulse strength of the insulation.

The dielectric strength of some faults is surprisingly high and may be increased further by pressure from adjacent wire. For this reason 25 per cent of the 5-foot d-c strength is suggested as the lowest voltage at which such tests should be made. The faults described and tested in the foregoing are not common in well-organized factories but it is possible for such faults to withstand tests as high as 33 per cent of the 5-foot d-c strength without failure.

Because of these voltage limitations to high voltage d-c testing it is important to increase the effectiveness of the testing as much as possible, by such means as increase of the soaking time and decrease of the pressure from adjacent wire.

Table IV. Dielectric Strength of Artificial Faults

	D-C Strength in Volts Per Mil Thickness					
Needle diameter, inch	0.025	0.025	0.025	0.050	0.057	0.042
Type of needle point	Extra fine	Fine	Medium	Medium	Blunt	*
	205	159	142	200	68	27
	225†	230	139			
	385**†					

* Hole made with 0.042-inch twist drill.

** Insulation stretched by bending wire before puncturing insulation. Wire then straightened and bound to a splint.

† No failure after 40 minutes on 20 kv (5 minutes plus, 5 minutes minus, 15 minutes plus, 15 minutes minus).

Table V. Effect of Pressure on Strength of Artificial Faults

Test Specimen	D-C Strength in Volts Per Mil After 24 Hours in Water
Needle fault with no pressure	135
Needle fault squeezed against one adjacent wire without fault by wooden clamp	170 310
Needle fault squeezed in group with three other wires without faults, by binding with cotton string	340 690
U-knife cut fault squeezed in group with 6 other wires without foregoing faults	600 then 480

Dangerous Electric Currents

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Synopsis: This paper discusses lethal electric currents and their accompanying physiological effects, and interprets the data of a previous paper[1] in accordance with an original method of analysis found useful by the author in his own investigations of let-go currents. The present analysis concerns itself with threshold currents likely to produce instantaneous electrocution in one-half per cent of a large group of normal men. Although the conclusions are derived from tests made on animals, it is believed that the results may be indicative of what might be expected to occur in man. The majority of the work is based on experiments made at 60 cycles with shock durations of 0.03 to 3.0 seconds. Predictions of lethal currents for both direct current and capacitor discharges, while more speculative because of the limited data available, are included because of their importance due to the greatly increased use of direct current and electronic equipment.

PROGRESS in the development of electric equipment has brought increasing demands for additional knowledge on the effects of electric shock, particularly with regard to the maximum current that man reasonably might be expected to withstand without fatal results. Sensations, muscular contractions, and the current required to cause the victim to freeze to a circuit have been covered fairly well in recent papers on let-go currents.[1,2,3] The object of this paper is to extend the analyses and discuss effects at higher currents.

Any definition of lethal currents must consider the following factors:

1. Current pathway through the body.
2. Physical condition of the victim.
3. Magnitude of the current.
4. Shock duration.
5. Frequency.
6. Wave form.
7. The phase of the heart cycle at the instant the shock occurs.

Electric shocks produce different effects depending upon the structure through which the current passes. Currents flowing in the region of the heart may produce a condition of the heart muscle known as ventricular fibrillation. This condition usually is fatal and commonly is referred to as instantaneous electrocution. Currents passing through nerve centers controlling breathing may produce respiratory inhibition, that is, stoppage of respiration. Failure of the breathing mechanism often is temporary, the paralysis lasting from a few minutes to a few hours after interruption of the current. These victims often may be saved by prompt application of artificial respiration. Currents passed across the head from temple to temple may produce unconsciousness and muscular convulsions. Shocks of this type are used currently in electric shock treatment in certain types of insanity. If the current pathway involves lower nerve centers, the shock might produce ejaculation. Electric ejaculation and artificial insemination apparently have promise in breeding animals. If the pathway involves only an extremity, such as a hand or leg, memory of a disagreeable experience might be the only lasting result. Because of such variations in the effects of electric shock, it is customary to discuss lethal currents with respect to the most dangerous current pathway likely to be experienced in accidents. This is a pathway involving the heart, with external contacts usually assumed between the hands, or between one hand and the opposite foot.

Much attention has been given the study of fatal accidents. These studies have been very helpful in developing practical safety procedures and safety codes. From a technical point of view, results have been qualitative rather than quantitative. This is largely because of the difficulty of determining accurately the many variables involved. In addition to the factors already mentioned, it usually is possible only to make rough estimates in arriving at values of circuit impedance, body and contact resistances, and elapsed time between occurrence of the accident, rescue, and resuscitation.

Often these uncertainties have resulted in erroneous conclusions and have confused the issue. Perhaps the most serious misconception concerns the effects of voltage versus the effects of current. Current and *not* voltage is the proper criterion of shock intensity. The remainder of this paper will be devoted to a discussion of the electric shock hazards, caused by currents of various shock durations, wave shapes, and frequencies.

Sixty-cycle currents at the let-go level, that is, currents of from 10 to 20 milliamperes from hand to hand, are painful and hard to endure for even a short time. If long continued, they may lead to collapse, unconsciousness, and death. The physical condition of the victim is of prime importance in determining this hazard. The muscular contractions and accompanying sensations increase in severity as the current is increased. The muscular contractions progress up the arm to the chest until they become so severe that the victim is unable to breathe. Obviously, if the current flows for more than a few minutes, death may result from asphyxiation. However, if the circuit is interrupted in a reasonable time, breathing resumes automatically, and no serious after-effects result. Currents considerably in excess of those required to cause a stoppage of breathing by excessive muscular contraction of the chest muscles may produce a temporary paralysis of respiration by action on the nerves. It has been known for some time that respiration might be inhibited by currents passing through the respiratory nerve center located in the base of the brain. Observation of temporary muscular paralysis in human accidents has prompted Howard Miller, Southern California Edison Company, to suggest that respiratory inhibition also might be caused by currents affecting the nerve centers controlling the diaphragm. The suggestion is in agreement with W. Einthoven, who some 30 years ago demonstrated that electric currents applied directly to a nerve, insufficient to cause permanent damage, could produce complete blocking of the nerve for periods of the order of one-half hour. The respiratory paralysis may last for a considerable period after interruption of the current. In this case, resuscitation must be applied immediately to prevent asphyxial death. Often the paralysis disappears in a few minutes or in a few hours, and continued application of artificial respiration may save the victim. Mere cessation of natural breathing is not likely to produce serious aftereffects or permanent damage, as evidenced by the many persons who have been resuscitated successfully.

Much valuable information on currents producing ventricular fibrillation

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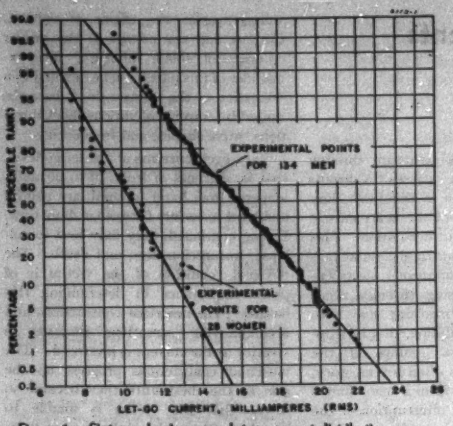

Figure 1. Sixty-cycle sine wave let-go current distribution curves for men and women

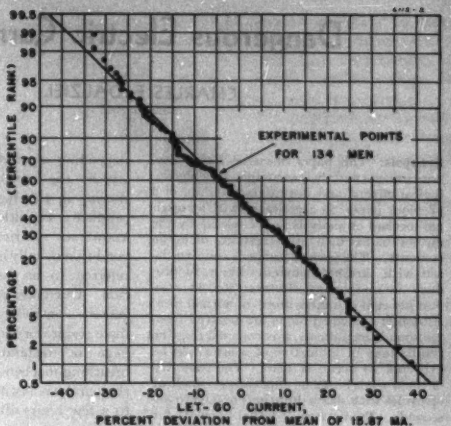

Figure 2. Sixty-cycle sine wave let-go current deviation curve for men

has been obtained from extensive experiments performed on animals at Columbia University by Ferris, King, Spence, and Williams.[4] These authorities adeptly have described the fibrillating condition as follows:

"Currents somewhat greater than those just necessary to stop respiration by action on the muscles may cause fatalities, even though the duration of such shocks is but a few seconds or less—far too short to be important from the standpoint of interruption of respiration, and obviously too short to give any opportunity for rescue before the end of the shock. Death under such conditions is brought about by ventricular fibrillation, which is a disruption of normal heart action. This condition is an uncoordinated asynchronous contraction of the ventricular muscle fibers in contrast to their normal co-ordinated and rhythmic contraction. It results from an abnormal stimulation rather than from damage to the heart. In the fibrillating condition, the heart seems to quiver rather than to beat; no heart-sounds can be heard with a stethoscope—the pumping action of the heart ceases; failure of circulation results in asphyxial death within a few minutes."

Most of the experiments were made on sheep, calves, pigs, and dogs, in which chest dimensions, body weights, heart weights, and heart rates were comparable to those of man, although several species of smaller animals, including guinea pigs, rabbits, and cats were included to establish the general trend of effects with weight and other physiological factors. Foremost of their findings from the practical point of view are:

1. The susceptibility of the heart to fibrillate depends on the phase of the heart cycle at the instant the shock is applied.

2. Repeated shocks are not cumulative in their effects on the heart, and the heart generally returns to normal in about five minutes if fibrillation does not occur.

3. The results on the whole indicated that sinusoidal currents in excess of 100 milliamperes at 60 cycles from hand to foot would be dangerous for shock durations of three seconds or more.

The statement establishing the threshold current producing ventricular fibrillation in man at 100 milliamperes for 60-cycle sine-wave shocks of three seconds or more has been accepted quite generally by the profession. Without any thought of depreciating the value of this conclusion, it is fair to say that much is to be desired yet in the way of additional information, with special regard to the variation of effects with shock duration, wave form, and frequency.

Before proceeding with the proposed analysis of fibrillating currents, it is helpful to review briefly certain conclusions found in the let-go current investigations.[2,3]

Experimental points representing let-go currents for 134 men and 28 women are shown in Figure 1, in which the ordinate gives the percentage of subjects who can release their grasp of a conductor carrying the current shown in the abscissa.[2,3] It is important to emphasize that a sufficient number of points was obtained to determine a normal distribution, as evidenced by the fact that the data closely follow a straight line when plotted on probability paper. Figure 2 shows the results for the 134 men plotted as per cent deviations from 15.87 milliamperes, the mean of the group. The straight line governed by the majority of the points of Figure 2 has been called the deviation curve. When points representing the women were plotted as per cent deviation from the mean of their group, it was found that they followed a deviation curve having the same slope. Similar results were found for composite waves consisting of a mixture of alternating current and direct current, for rectified 60-cycle sine waves, and for sine-wave alternating currents from 5 to 5,000 cycles. This finding is important because it permits improved accuracy in predicting results for large groups based on a relatively small number of experimental points.

This procedure will be used now to study 60-cycle fibrillating currents obtained by Ferris and his associates. Figure 3 shows fibrillating currents plotted as per cent deviations from the mean of each series, respectively, for eight different tests. Although the distribution of the points does not line up as well as that found for let-go currents, it does establish that a definite trend exists. This holds for the four species of animals for 3-second shocks, and for the sheep for shock durations of 0.03 to 3.0 seconds. It is possible that the same trend also might hold for shocks of various durations for the other animals and for man.

Because of the small number of points available for any test, the straight line governed by all the points was drawn to determine the deviation curve. Apparent discrepancies of a few of the points

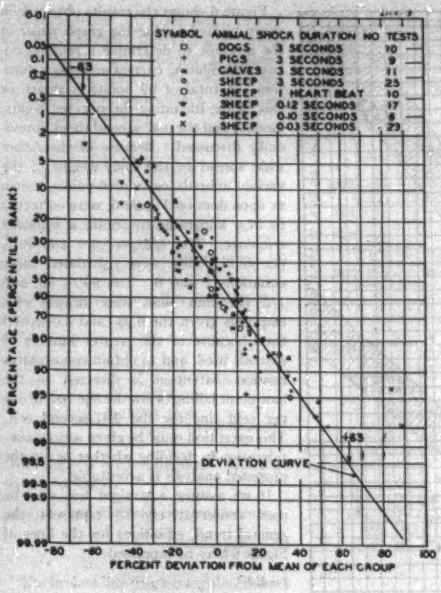

Figure 3. Sixty-cycle sine wave fibrillating current deviation curve for various animals

from the deviation curve are believed to be caused by the small number available for any single test, to experimental errors in applying the shocks at the most susceptible phase of the heart cycle, to the rather wide variation in body weights, and to other factors which properly are included in the term biological variability.

The fibrillating current for an animal was taken as 1/2 (minimum current causing fibrillation + maximum current not causing fibrillation). It is believed that the value so obtained should be reasonably close to the current just required to produce fibrillation during the most susceptible phase of the heart cycle, and the statistical method of analysis should minimize errors.

The current pathway for these experiments was between the right foreleg and the left hind leg. Experiments also were made using four other pathways, namely, across the chest, chest to foreleg, head to hind leg, and between both hind legs. For the current pathway between the two hind legs, the portion of current reaching the heart was evidently too small to produce fibrillation for currents within the operating range of the equipment. Differences in values for the other pathways did not appear great enough to be significant, and it was concluded that results obtained for the pathway between the foreleg and the hind leg should be sufficiently accurate for most engineering purposes.

Data obtained by the investigators at Columbia University[4] for 129 points were furnished the author. Of this number, 111 were used and 18 omitted in the statistical analysis. The points rejected represented two different conditions. Eight high points, designated by these investigators as mode *A*, were omitted to give conservative results. The remaining ten points were from the 0.47-second shock test made on sheep.

The following is submitted as justifying rejection of the 0.47-second test:

1. Results of the 0.47-second shock test are shown in Figure 4 in which the response follows a deviation curve of much smaller slope than that found for the other tests. Wide differences in the results of two almost identical tests suggest the possibility of error. The points representing shocks of one heartbeat (large open dots, Figure 3) are consistent with all the other tests, and fall very nicely about the deviation curve. The duration of the shocks for this test was adjusted to equal as nearly as possible the time of the individual's heartbeat and varied from 0.36 to 0.55 second, averaging 0.45 second. It is untenable that a difference of only 0.02 second in the average shock duration would be sufficient to cause the difference in response indicated by the two deviation curves.

2. The accuracy of analyses based on statistical procedures depends upon a representative number of points. It was difficult to establish deviation curves for let-go currents for less than about 25 points. The apparent inconsistency of a single test involving only 10 points therefore is not considered sufficient to invalidate the analysis.

Fibrillating currents for three-second shocks for seven species of animals versus body weight are shown in Figure 5. Points representing the larger animals total 55, and none were discarded. The smaller animals were represented by average values only, as data for these cases were not furnished the author. The 50 per cent line was drawn by inspection through the points representing the means of the various tests. The author is still in doubt as to where to draw the best line, and the analysis was carried on from here, using a broken line neglecting the points for the pigs, and a solid line in which the effect of the pigs was weighed by eye. The fact that the upper line passes very close to the points representing the averages for each of the other six tests is believed significant. It is unfortunate that only nine pigs were used.

In spite of the wide scattering of individual points, it is evident that in general the fibrillating current is proportional to body-weight. Similar variations were encountered when studying let-go currents, but all efforts to find a correlation with age, weight, strength of grip, or arm measurements, were without conclusive results; however, higher values were obtained on well-developed individuals having the appearance of good health. Other things being equal, it is believed that both let-go currents and

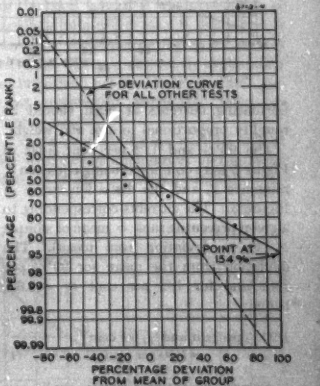

Figure 4. 60-Cycle sine wave fibrillating current deviation curve for sheep

Shock duration 0.47 second
Ten cases tested

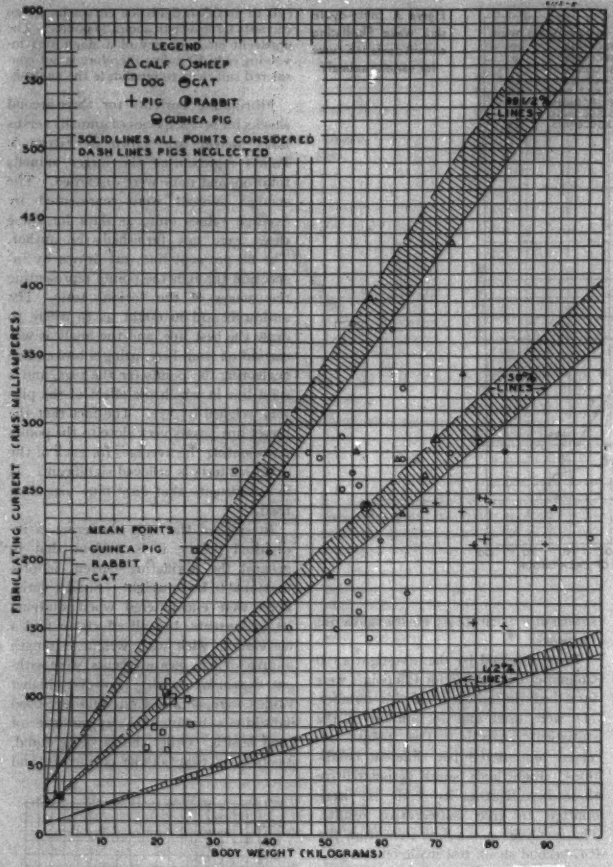

Figure 5. Relation of 60-cycle sine wave fibrillating current of various animals to body weight

Shock duration 3.0 seconds

fibrillating currents at least should be roughly proportional to size and weight.

The 99½ and 1/2 per cent lines of Figure 5 were computed using equation 1, reference 2, and the deviation curve of Figure 3. The currents corresponding to a given percentile rank = mean of sample × (1 ± deviation from mean). The deviation from the mean for 99½ per cent and for 1/2 per cent = ±0.63, hence:

$$I(99\tfrac{1}{2}\text{ per cent and }\tfrac{1}{2}\text{ per cent}) = I(50\text{ per cent})(1 \pm 0.63) \quad (1)$$

Assume that the analysis applies to man. Enter the graph at 70 kilograms which is the weight of an average man, and proceeding vertically indicates that 60-cycle sine-wave alternating currents between 95 and 107 milliamperes and three seconds duration might produce ventricular fibrillation in one half of one per cent of a large group of normal men. This is in close agreement with the generally accepted figure of 100 milliamperes proposed by Ferris, King, Spence, and Williams.[4]

The equation for the lower one half per cent line may be written:

$$I(\tfrac{1}{2}\text{ per cent}) = 1.26W + 7.4\text{ milliamperes} \quad (2)$$

in which W denotes body weight in kilograms.

Figure 6 shows the results obtained on sheep plotted on log–log graph paper in the attempt to determine a relation between fibrillating current and shock duration. A total of 99 points is shown in this figure, including the rejected points, mode A and the 0.47-second shocks previously discussed. Because of the rather wide spread in the body-weight of the various animals, calculated points, shown as open dots on Figure 6, were corrected to 57.4 kilograms to obtain a standard reference. The 1/2 per cent and 99½ per cent points were calculated using equations 1 and 6. The 99½, 50, and 1/2 per cent lines were drawn with emphasis given the 0.03- and 3.0-second tests because of the greater number of animals used, and to obtain conservative results. Attention is directed to the lone point falling below the one half of one per cent line for the 0.47-second test. This exception must be given serious consideration in deciding whether or not the proposed analysis is acceptable.

If we assume a straight line may be used conservatively to represent the general trend, equations for the lines of Figure 6 may be expressed:

$$I = KT^n,$$

where

n = slope = $-1/2$

T = shock duration in seconds

Therefore

$$I = \frac{K}{\sqrt{T}} \qquad K = I\sqrt{T} \quad (3)$$

The equation for I(1/2 per cent) for 57.4-kilogram sheep is found as follows. From Figure 5, when T = 3 seconds, I(1/2 per cent) = 89.5 milliamperes. Substituting in equation 3,

$$\left.\begin{aligned} &K = 89.5\sqrt{3} = 155\text{ milliamperes} \\ &I(\tfrac{1}{2}\text{ per cent})\text{ sheep} = \frac{155}{\sqrt{T}}\text{ milliamperes} \end{aligned}\right\} \quad (4)$$

The I(1/2 per cent) equation for all 57.4-kilogram animals is found as follows. From Figure 5, I(50 per cent) sheep = 240.5 milliamperes, and W = 57.4 kilograms. The mean fibrillating current for the solid line for a weight of 57.4 kilograms = 215 milliamperes. The corresponding 1/2 percentile value is 89 × 215/240.5 = 79.6 milliamperes. Therefore,

$K = 79.6\sqrt{3} = 138$ from equation 3

Therefore, for all 57.4-kilogram animals tested, including sheep,

$$I(\tfrac{1}{2}\text{ per cent}) = \frac{138}{\sqrt{T}}\text{ milliamperes} \quad (5)$$

Equations for $I(1/2$ per cent), including effects of shock duration and various body-weights, are obtained as follows. Let subscripts 1 and 2 be used to represent animals 1 and 2, respectively. Equation 2 then may be written

$$\frac{I_1(1/2 \text{ per cent})}{I_2(1/2 \text{ per cent})} = \frac{1.26W_1+7.4}{1.26W_2+7.4}$$

or

$$I_1(1/2 \text{ per cent}) = I_2(1/2 \text{ per cent}) \times \frac{1.26W_1+7.4}{1.26W_2+7.4} \text{ milliamperes} \quad (6)$$

Substituting equation 5 in equation 6,

$$I(1/2 \text{ per cent}) = \frac{138}{\sqrt{T}} \times \frac{1.26W+7.4}{1.26\times 57.4+7.4} \text{ milliamperes}$$

$$= \frac{2.18W+12.8}{\sqrt{T}} \text{ milliamperes}$$

Inserting $W=70$ kilograms (average weight for man),

$I(1/2$ per cent) fibrillating current for man

$$= \frac{165}{\sqrt{T}} \text{milliamperes} \quad (7)$$

The broken line (neglecting the effect of the pigs) of Figure 6 was obtained by substituting equation 4 in equation 6 and $W=$ 70 kilograms. It is interesting to note that the uncertainty of the current versus weight-lines of Figure 5 produces an inappreciable difference in the final result, as indicated by the small width of the crosshatched area of Figure 6.

It should be repeated that this analysis is based on experiments in which the duration of the shock was varied from 0.03 to 3.0 seconds. Extrapolation for larger range of shock durations should be made with caution; possibly the relations might hold for durations from five seconds to one cycle or possibly one fourth cycle. No account is taken here of inhibition of respiration or of the cumulative effects of shocks at intervals of the order of seconds. These relations are based on the assumption that the heart recovers fully from one shock before a second shock occurs. In other words, the threshold currents are for single shocks. No data are available regarding the effects of repeated shocks such as those produced by intermittent electric fence controllers.[6,4] It must be stressed that application to man is entirely conjectural.

Relatively large currents (amperes and not milliamperes) may produce sufficient heat to destroy nerves, protoplasm, bone and cause hemorrhages resulting in immediate death. Delayed death may

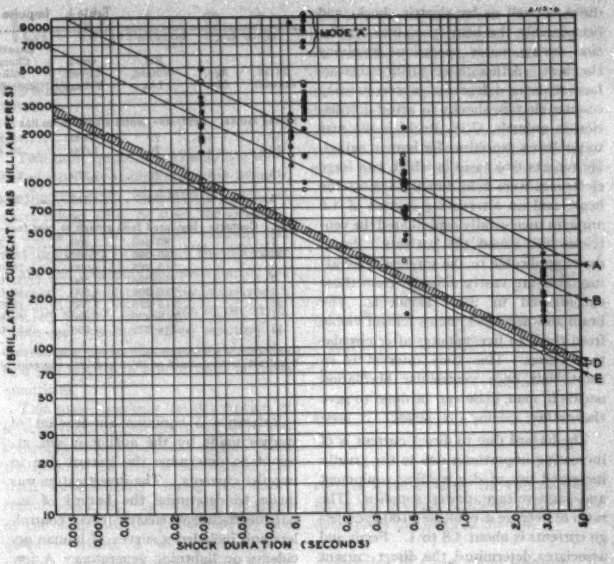

Figure 6. Relation of 60-cycle sine wave fibrillating current to shock duration

- Experimental points
- Calculated points

A—99½ per cent line for 57.4-kilogram sheep
B—50 per cent line for 57.4-kilogram sheep
C—½ per cent line for all 70-kilogram animals including man
D—½ per cent line for 57.4-kilogram sheep

be due to burns or other complications.

For 0.03-second shocks, the hearts of sheep seemed to be most susceptible to fibrillate at currents of about six amperes, and less sensitive as the current was either increased or decreased from this value. Figure 7 was taken from reference 4 to illustrate the point. The explanation of this phenomenon is that high currents cause complete contraction of the entire heart musculature, and fibrillation is prevented. If the shock is of appreciable duration, death is inevitable. However, if the shock is of short duration, when the current is interrupted, relaxation may be followed by a spontaneous resumption of normal rhythmic contractions. It is believed that the abdominal massage and accompanying stimulation of the heart caused by the application of artificial respiration may be beneficial in assisting the heart to regain its normal rhythm. This is offered in explanation of infrequent accident cases in which victims apparently withstand relatively large currents.

Ventricular fibrillation may be caused by mechanical stimulation of the heart when it is exposed during surgical proce-

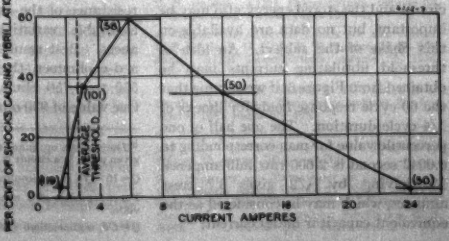

Figure 7. Effect of current on susceptibility of sheep hearts to ventricular fibrillation

Shock duration 0.03 second frequency 60 cycles. Shocks applied in partial refractory period of cardiac cycle. Number of shocks and current spread indicated for each point on curve

dures as well as by electric shock, and occasionally the heart goes into fibrillation during major operations involving the chest. Although several investigators have reported a degree of success in using counter-electric shocks to arrest fibrillation in animals, C. S. Beck[7] is the first to publish a procedure for human beings. He reports two cases in which two large electrodes were held directly against the heart and an alternating current of 1.5 amperes successfully defibrillated the ventricles and saved the patients. Procedures applicable to the surgeon's operating table are vastly different from those encountered in most accidents. The brain and nervous systems remain viable from three to five minutes after circulation ceases. This time interval is so short that once ventricular fibrillation occurs in man, little can be done to save the victim.

The hazard due to direct current is of increasing importance due to the greatly increased use of d-c welding equipment and high-voltage power supplies. The ratio of average d-c release to 60-cycle let-go currents is about 4.8 to 1. Ferris and associates determined the direct current required to produce ventricular fibrillation in 11 sheep for 3-second shocks. The ratio of average d-c to a-c fibrillating current was 5 to 1. This information, although obtained for only 11 animals, is the only quantitative data available on fibrillating direct current. It is to be expected that the fibrillating current for very short shocks would approach the 60-cycle crest value. This is a ratio of $\sqrt{2}$ to 1. If we assume that the lines of Figure 6 apply for durations as short as one fourth cycle, that is, 0.0042 second, a second value may thus be established. A series of straight lines for direct current shocks similar to those of Figure 6 could be drawn, using the factors 5 and 1.41 for shock durations of 3.0 and 0.0042 second, respectively.

The danger from capacitor discharge is of vital importance. It generally is believed that the initial current and charge are of prime importance in determining the hazard. The time constant of the circuit and the stored energy also may be important, but no data are available on this phase of the subject. An idea of threshold fibrillating currents may be obtained from Figure 6, if we assume that the 60-cycle response holds for shocks of 1/4-cycle duration. The one half of one percentile value for man corresponding to 0.0042 second is 2,600 rms milliamperes. Multiplying by $\sqrt{2}$ gives 3.7 crest amperes, which may be considered as the equivalent capacitor initial current.

Table I. Impulse Tests on Animals

No. of Animals	Age, Mos	Est. Weight, Lbs	Open Circuit Voltage	Capacitor Charge, Millicoulombs	Animal Resistance, Ohms	Avg. No. of Shocks	Remarks
Spring lambs. Contacts—metal electrods on lips to rear feet in bucket of salt water							
10	4–6	72	1,400	18.2	550–1,750	3	
10	4–6	70	1,600	20.8	550–1,750	3	Three sheep stunned for 5–15 sec*
13	4–6	72	1,750	21.0	550–1,750	3	One sheep stunned for 5–15 sec*
6	4–6	72	1,750	22.7	550–1,750	2	One sheep stunned for 5–15 sec*
Pigs. Contacts—insulated feed trough to rear feet on wet earth							
1		180–200	1,400	4.2		4	
25		180–200	1,400	7.0		4	
1		215–225	1,000	10.0		1	
2		215–225	1,200	12.0		1	
1		215–225	1,600	16.0		1	
25		215–225	1,750	17.5		1	
1		215–225	1,400	16.8		1	
12		215–225	1,750	21.0		1	One pig stunned for 60 sec*

* Animals were stunned on third or fourth consecutive shock.

Reference 5 contains an account of studies made by the author in the attempt to determine the hazard due to impulse currents. The investigation was made to determine the hazard of capacitor-discharge electric-fence controllers and included a survey of human accidents on lightning generators. A few capacitor discharge tests were made on male volunteer subjects on voltages up to 1,750. Impulse tests using larger capacitors were made on spring lambs and pigs. Table I shows some of the data obtained from tests made on the animals. No fatalities were experienced and higher power was not used because of limitations of equipment. No attempt was made to co-ordinate the shocks with the sensitive phase of the heart-cycle. However, because of the large number of shocks applied, it is reasonable to assume that they were distributed throughout the heart-cycle, and probably many occurred during the sensitive phase. It would seem that the highest currents given the smallest animals might give some idea of reasonably safe upper limits. The average weight of the spring lambs was 72 pounds or 32.6 kilograms, maximum voltage 1,750, and maximum charge 22.7 millicoulombs. Considerable difficulty was experienced in measuring the body-resistance of the animals because of unavoidable variations in contact resistances. Best results were obtained using a d-c ohmmer, the values ranging from 550 to 1,750 ohms. Using a conservative value of 930 ohms for circuit, animal, and contact resistance, equation 6 gives an initial current of 3.7 amperes which compares with that suggested in the preceding paragraph. If we assume that equation 6 holds for both current and charge, the corresponding value for man is 45 millicoulombs.*

The criterion proposed for defining dangerous current thresholds is based on the current which might produce ventricular fibrillation in one half of one per cent of a large group of normal adult men. The choice of course is arbitrary, and any other number could be selected. There is no intention to be ruthless about the remaining one half per cent; however, one has to stop somewhere, and the 1/2 percentile was considered a reasonable stopping point. Perhaps the best justification for choosing the 1/2 percentile is that it was used in estimating reasonably safe let-go currents and provoked no adverse comment.[1,2,3] As previously mentioned, all available experimental data were analyzed carefully, and in instances which required special judgment (such as just where to draw the best line to determine the general trend of a response), an attempt was made to adopt procedures which would give a conservative final result. Several different attempts were made to correlate the data, but the method proposed is believed to be the best that can be done. It is indeed unfortunate that statistical predictions must be expressed numerically, as there is a tendency to place too much emphasis on mere numbers. Quite aside from the uncertainties of the present analysis, there remains the important uncertainty of transferring results obtained from animal experimentation to man. However, data from numerous human accidents, although meager and inconclusive, seem to

* The charge or quantity of electricity passing a given point in a circuit is given by:

$Q = 10^{-3} \int i \, dt$ millicoulomb (milliampere-seconds)

For a capacitor of C microfarads charged to E kilovolts,

$Q = CE$ millicoulomb (milliampere-seconds)

An Electronic Drive for Windup Reels

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REELING OPERATIONS impose a number of special requirements on the reel drive, particularly if the latter is of the so-called core type as compared to the rather rarely used peripheral type drive.

In a core type drive the reel is driven through a center axle on which it is mounted. This type is usually preferred to the peripheral type drive which involves traction along the periphery of the reel and thus requires a direct contact and a sufficiently high tangential force exerted upon the material being wound. It is apparent that, although the peripheral drive usually will represent a much simpler electric system since it is not influenced by the change in the diameter of the reel, it is often undesirable or even impossible to transmit the driving torque directly through the material involved in the winding operation.

The core type drive, on the other hand, does not present these disadvantages, and is used most commonly, although it normally involves other problems and the resulting complications of the electric system.

Two basic quantities usually are associated with any reeling operation where a continuous strip of material such as yarn, fabric, wire, or steel, for example, is drawn by the so-called take-up reel and wound on it, so that the diameter of the reel gradually increases during the process. The first quantity is the speed, and the second, the tension of the strip. Some reel systems impose exacting requirements as to the automatic regulation and control of one or both of these quantities.

This paper presents the description of a recently developed electronic drive and control for a core type take-up reel where the speed of the strip is maintained constant automatically during the entire reeling operation. In addition, the speed of the strip can be preselected by the operator within a wide and stepless range. The problem of tension of the strip is not considered here. In many of the applications, tension of the strip is of secondary importance, and proper control of speed is a fundamental requirement. Furthermore, tension regulating devices always can be added, if so required, by proper control of the unwinding reel. The drive described in this paper has been developed for take-up reels in systems where the reel also performs the drawing of the strip and thus determines the speed of the line.

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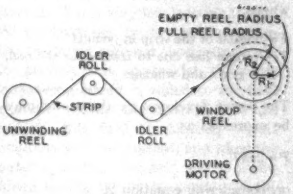

Figure 1. Outline of a windup reel system

Principles of Core Type Reeling

In Figure 1 is shown schematically a take-up reel with its minimum and maximum diameters. The radius of the reel builds up during the reeling operation from a minimum value R_1 to a maxi-

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indicate that the proposed threshold values are conservative. It is the author's opinion that currents much in excess of the proposed threshold values must be considered very dangerous to human life. Perhaps, at some future date, sufficient time and funds may be available and a more accurate solution be obtained.

We are indebted to H. B. Williams for the following discussion of effects at high frequency. On sinusoidal high-frequency alternating currents, or on repeated current pulses of very short duration, account must be taken of the fact known to physiologists that, as the shock duration decreases, its strength must be increased in order to produce the same stimulation. As the duration becomes very small, this increase must be very great, finally becoming so great that destruction of living substances may occur before it can respond. At higher frequencies, large currents may pass without causing stimulation of muscles or nerves, and these may cause deep heating effects. Since the heat-sensitive mechanism is located in the skin, there is a possibility of damage to internal organs by high-frequency currents even though no very unpleasant sensations may be apparent. The currents necessary to produce this effect would be in the order of an ampere or more. High-frequency currents of several hundred milliamperes are used quite commonly by the medical profession for deep heating. This form of treatment is called medical diathermy.

In concluding, it should be mentioned that, because of the wide variation in the physical condition of individuals, an occasional death is to be expected from casual contact involving electric currents known as safe for most normal, healthy individuals, but these are probably not fibrillation deaths. It is gratifying indeed that victims surviving the initial shock of an electrical accident seldom suffer serious aftereffects or other permanent disability. Since it is impossible for the layman to distinguish between respiratory inhibition, ventricular fibrillation, and heart failure, he should begin artificial respiration immediately and summon medical aid as soon as possible.

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mum value R_0. The speed of the strip may be expressed by the following equation

$$v = 2\pi nR \text{ feet per minute} \quad (1)$$

where

n = motor speed in revolutions per minute
R = instantaneous radius of the reel in feet

The torque developed by the motor

$$T = FR + T_0 \text{ pound-feet} \quad (2)$$

where

F = tension of the strip in pounds
T_0 = torque loss due to friction in the reel, gears and windage

The power developed by the motor may be expressed as

$$P = 2\pi nT$$

or, considering equation 2,

$$P = 2\pi n(FR + T_0)$$
$$P = 2\pi nRF + 2\pi nT_0 \quad (3)$$

The first term of equation 3 obviously represents the useful power required to draw the strip, and is the product of the strip speed v, and strip tension F. The second term, which is the product of the motor angular speed and the friction torque of the reeling system at the motor shaft, represents the loss of power of the reeling system. Thus, the efficiency of the reeling system

$$\eta = \frac{1}{1 + \frac{T_0}{RF}} \quad (4)$$

It is apparent from equation 1 that in order to maintain constant line speed v, the speed of the driving motor must change in inverse proportion to the diameter of the reel. On the other hand, if the friction torque T_0 is neglected, then the power required during the reeling operation

$$P = vF = 2\pi nRF = \text{constant}$$

Thus, if a constant line speed is to be maintained during the reeling from an empty reel with a radius R_1, to a full reel with radius R_2, the speed of the driving motor n corresponding to any intermediate radius R of the reel should be

$$n = n_1 \frac{R_1}{R} \quad (5)$$

where n_1 is the motor speed for an empty reel.

As was mentioned previously, the power requirement imposed on the drive during reeling remains essentially constant and, consequently, the most adequate and economical way of obtaining the required speed control is by controlling the field excitation of a d-c shunt-wound motor.

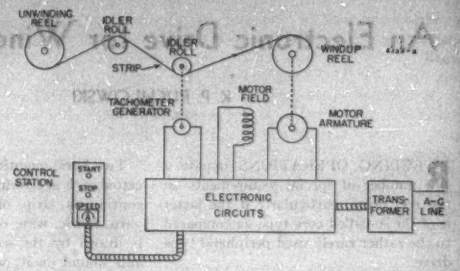

Figure 2. General scheme of the electronic drive for windup reels

Another type of speed control is necessary to provide an adjustable strip speed, and it is often required that a speed range as wide as ten to one be provided by the drive. Here, if an approximately constant tension is assumed, for any given radius of the reel, the required torque is independent of the line speed (see equation 2), and the required horsepower is directly proportional to the line speed v (if the friction torque T_0 is neglected). Consequently, the armature voltage control of a d-c shunt-wound reel motor is the most suitable means of obtaining the control of the strip speed.

A clear distinction between the two types of the reel-motor speed control should be specifically emphasized. For any given diameter of the reel, the line speed should be adjustable by armature voltage control of the driving motor, and the speed of the motor should remain constant for a given excitation and a given speed setting, even if the torque is varied within wide limits. This speed control should not respond to changes in the diameter of the reel.

The second type of speed control should respond automatically to any change in the diameter of the reel, so that with increasing diameter, the excitation of the motor should increase automatically to slow the motor down just enough to prevent the speed of the strip from being increased. The field control of the motor should not respond, generally speaking, to any change in line speed obtained through the armature voltage control.

Basic Control System

To maintain a constant strip speed with varying diameter of the reel, an electronic field regulator is incorporated into the system. The term regulator, or servomechanism means an automatic control system characterized by a closed cycle of interdependence of quantities involved, so that a slightest deviation of the regulated quantity from the predetermined value results in the appearance of the so-called restoring force, which acts in the direction to oppose any change in regulated quantity, or, if some change has already occurred, to restore the quantity to its original value. Actually, the most accurate and sensitive regulator is unable to restore the deviated quantity to exactly its original value, when a definite cause for the deviation exists. This is so because the regulator creates a restoring force or "back-to-normal" action only in response to some existing deviation, and a new balance of the system always will be established only with the existence of some deviation. However, a satisfactory regulating system will reduce the deviation to such a minimum that, depending upon the application, it may be assumed to be negligible.

Any regulator is characterized by the following four basic elements which form the links of the previously mentioned closed cycle of interdependence of quantities:

1. Indicator of the regulated quantity.
2. Standard reference quantity with which the regulated quantity is compared.
3. Amplifier which originates a sufficiently strong restoring force even for minor deviations of the regulated quantity from the prescribed value.
4. Restoring force which manifests itself in an action opposing any deviation of the regulated quantity.

In addition, a regulator may have a number of secondary elements such as damping (antihunting) and anticipatory elements which play a vital part in the stability and the time of recovery of the regulating system.

The electronic reel drive is shown schematically in Figure 2. A tachometer generator driven by the strip through an idler roll is used as the indicator of the regulated quantity, that is, of the line speed. Since this generator is required to deliver only negligible

power, its size may be small and, consequently, its WR^2 and losses equally small. The preferable tachometer generator is a d-c permanent-magnet type, as here there is no need to provide separate excitation or, as in the case of an a-c type, to amplify and then rectify the output to make it a useful indication of speed. Besides, the permanent-magnet type tachometer generators usually have an excellent voltage–speed characteristic. The output voltage of a d-c permanent-magnet tachometer generator represents a linear function of its speed, particularly when the current output is negligible. The voltage output is relatively high, of the order of 50 volts per 1,000 rpm, and for all practical intents and purposes, independent of temperature changes or any other external influences. A typical voltage–

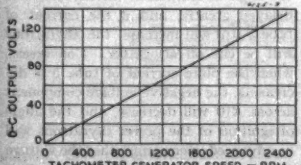

Figure 3. Typical output voltage of a d-c permanent magnet tachometer generator

speed characteristic of a permanent-magnet tachometer generator is shown in Figure 3.

The output voltage of the tachometer generator (see Figure 2) is introduced into the field control portion of the electronic drive where it is balanced or compared with a reference voltage. The difference of the two is then fed into an amplifier, and after the amplification, is used to control the output of a thyratron-exciter which supplies the field current to the reel motor. As it will be seen later, the control circuits are so designed that when the line speed tends to increase because of the increase in the diameter of the reel (see equation 1), the field of the motor is strengthened to slow the motor down in accordance with equation 5. This forms the previously mentioned closed cycle of interdependence of quantities, which is represented in Figure 4.

The armature power supply and armature control of the electronic drive is obtained by means of a controlled rectifier consisting of thyratron elements and various control circuits. These circuits provide a constant-speed characteristic so that for a given excitation of the field, the speed of the motor remains essentially constant for any variation of torque within the operating range of torque values. The armature control circuits are of the voltage regulated, IR drop compensated type. They provide a properly rising voltage–current characteristic and essentially constant speed–current characteristic. Current limit features also are incorporated in the armature control circuits, to take care of the starting and overload conditions of the drive.

In addition to a constant speed–torque characteristic, the armature control circuits provide means for adjustment of the motor speed by voltage control, and in that manner the strip speed can be changed. Each setting of the speed control dial corresponds to a different but strictly determined line speed, automatically regulated to stay constant and independent of the changes in the diameter of the reel. Usually, the line speed control dial is a small $1^1/_2$ inch in diameter potentiometer, assembled as a part of a separately mounted control station, which also includes other operator's controls such as start and stop push buttons and threading speed push button. The operator's control station usually is mounted remotely from the cabinet housing all the electronic controls and at a location most convenient for the operator. The armature control portion of the drive as well as the operator's control station is shown schematically in Figure 2.

Special Problems

Outside of system stability problems which are, of course, present in any regulating system and require special stabilizing means, the following two problems are of particular importance:

1. Field control during the acceleration.
2. Field regulator response to a change in line speed resulting from the readjustment of that speed by the operator.

Although these problems will be discussed in more detail later, in connection with the description of circuits, it seems appropriate to mention their nature in advance.

Referring to the acceleration problem, it should be noted that at the instant of starting the reel drive, the voltage output of the tachometer generator is zero. Furthermore, at the start of the reeling operation the reel is empty and, obviously, the driving motor and reel should accelerate to a maximum operating speed, corresponding to the lowest operating value of the motor field. Consequently, it follows that on starting of the drive, when the speed of the line is zero, the regulator, responding to a low speed signal of the tachometer, will naturally tend to decrease the field excitation of the motor to a minimum. Considering a relatively low value of starting current limited by the current limit circuit (see section on armature control) to about 200 per cent of rated armature current, it will become apparent that a very low starting torque will be developed by the reel motor so that the latter may not accelerate at all. To prevent this, a special electronic accelerating circuit is added to the field regulator. When the reel motor is not running, this field accelerating circuit maintains full field current, and when the motor is started, the field still is maintained during the initial portion of the

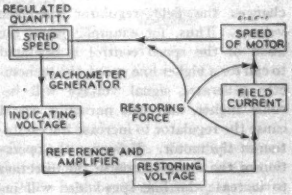

Figure 4. Cycle of interdependence of the strip speed regulator

accelerating period. Then the field current gradually is decreased exponentially with time, but, owing to a special electrical coupling between the armature and field control circuits, it never is allowed to decrease below a certain minimum value, as long as the armature current exceeds the rated value more than by about 50 per cent. As soon as the armature current drops to its normal operating value, indicating that the acceleration of the motor is completed, the action of the field accelerating circuit disappears, and the field current of the motor is controlled by the regulator through the tachometer generator which has by that time accelerated to its operating speed. From now on the regulation of the line speed proceeds as described previously.

The problem of the field regulator response to a change in tachometer generator signal, when caused by the readjustment of the line speed by the operator, deserves special attention. As pointed out before, the slightest change in the tachometer generator output voltage, indicating a change in line speed, normally

will result in the action of the regulator to properly change the motor excitation and its speed in such a way as to oppose any change in the tachometer generator signal voltage. However, if the change of the tachometer generator voltage is caused by the line speed change through armature voltage control, the regulator obviously should not respond to that change. In other words, when the change in the tachometer generator voltage is a result of the change in diameter of the reel, the regulator should respond and control the motor field, but for any given diameter of the reel, the field current of the motor should remain essentially the same for different line speeds.

This requirement is fulfilled by using two potentiometer units mounted in tandem as operator's line speed control. One of the potentiometer units is used in a regular manner as the armature speed control, the other properly changes the field regulator reference voltage. Thus, for example, when the knob of the speed control is operated to call for a higher line speed, the tachometer generator signal voltage will become higher, and this normally would cause the regulator to increase the excitation of the motor. However, the operation of the control knob in the direction to increase the line speed also will increase the reference voltage of the field regulator in such a manner that the difference between the two voltages will remain the same, and the field current will not be changed.

The voltage across the reference potentiometer of the regulator can be easily adjusted so that a change in line speed and in armature voltage is accompanied by a proper change in reference voltage of the regulator. In fact, this adjustment by no means is critical, and some small changes in the field current for different operating line speeds can be tolerated, since this will not produce any adverse effect on the operating or regulating properties of the drive.

Electronic Circuits of the Drive

A simplified schematic diagram of the electronic drive is shown in Figure 5. It includes all the elements necessary for the proper explanation of the principles of operation of the system. For the sake of simplification, details of various auxiliary d-c power supplies have been replaced by batteries. Heater circuits for all the electronic tubes have been omitted, and all the grid controlled tubes, both of the thyratron and high vacuum type, are represented as triodes. All the by-pass and filtering capacitors also have been omitted. The diagram covers the entire electric system of the reel drive and is divided distinctly into the armature control and the field control portions.

Armature Control Circuits

The armature control circuits are similar to those described and analyzed in detail in a previous paper.[1] They consist, as shown in Figure 5, of four major groups: the controlled power rectifier, master regulating and control circuits, *IR* drop compensating circuits and the current-limit circuits. The power rectifier circuit is shown as a symmetrical 2-phase rectifier (often called single-phase full-wave rectifier) although it may be also a 3-, 4-, or 6-phase unit, depending upon the horsepower rating of the drive. The rectifier consists of a center-tapped winding of the main transformer *T*1, two thyratron tubes 1 and 2, contacts *FCR* of the main contactor, fuses in the anode circuits, grid transformer *T*3, and current transformer *T*2. A phase-shift circuit consisting of a center-tapped winding of transformer *T*1, resistor *R*14, and capacitor *C*1 provides a voltage which lags the rectifier anode supply voltage by about 90 to 100 degrees. This lagging voltage is applied to the primary winding of the grid transformer *T*3. The grid control voltage of the thyratrons consists of an a-c component supplied by transformer *T*3 and a d-c component. The latter is applied between the cathodes of tubes 1 and 2, and the center tap of the grid transformer *T*3. During the control process the angle of ignition of the thyratrons is changed either automatically or manually by proper changes in the d-c component which may assume both negative and positive values so that the constant a-c component of the grid voltage, superimposed upon the variable d-c component, can be moved up or down and control the angle of ignition in a well-known manner.

Control of the d-c component of the thyratron grid voltage is obtained through the variable voltage across the load resistor *R*10 of the main control tube 5. If tubes 3, 4, and 6 are disregarded temporarily, it will be easy to notice that the armature system is an adjustable voltage regulator. Thus, the voltage across *R*2 is the indicator of the regulated quantity, being proportional to the armature voltage. The adjustable portion of the potentiometer *PA* represents the reference voltage. The *PA* voltage is negative with respect to the grid of tube 5 and the *R*2 voltage is positive. Since the voltage across the adjustable portion of *PA* always is higher by several volts than the voltage across *R*2, their difference applied to the grid of the master control tube represents a negative voltage of several volts.

The grid circuit of the thyratrons is completed from the cathodes through *R*2, *PA*, *R*12, *R*10, and *R*6 to the center tap of transformer *T*3. All the d-c components in that portion of the circuit essentially are constant except the voltage across *R*10 which changes with the plate current of tube 5, and performs the actual control of the angle of ignition of the power thyratrons. It is important to note that the direct voltage across *R*10 has a negative polarity with respect to the grids of thyratron tubes. Thus, when the plate current of tube 5 is high, the angle of ignition of the thyratrons is delayed greatly, and if the current of tube 5 still will increase, the thyratrons will be cut off altogether. Conversely, when the plate current of tube 5 is decreasing, the negative voltage component across *R*10 will decrease, and the angle of ignition of the power thyratrons will be advanced, increasing either the voltage or the current output of the armature rectifier, or both.

It is apparent that the voltage across *R*10 together with the grid control of the thyratrons represents the restoring force of the armature voltage regulating system, since any deviation of this voltage from the prescribed value will result in a response of the amplifier 5 and a change in voltage across *R*10 in the direction to oppose the deviation of the armature voltage. Furthermore, a change in the reference voltage obtained by the readjustment of *PA* will result in a change in rectifier voltage output so that a new balance of the system will be obtained at a different armature voltage, that is, a different speed of the motor. The difference between the reference and the indicating voltages, however, will not be changed appreciably because of the strong amplifying action of the regulating tube 5.

It is well known that if the armature voltage remains constant, for a constant excitation, the speed of the motor usually will drop with increasing torque, as is normally the case for shunt-wound motors. This drop is caused mainly by the *IR* drop in the armature circuit. Although this drooping speed–torque characteristic is usually not objectionable at rated motor speed, at lower speeds such as one-tenth of the base speed, a

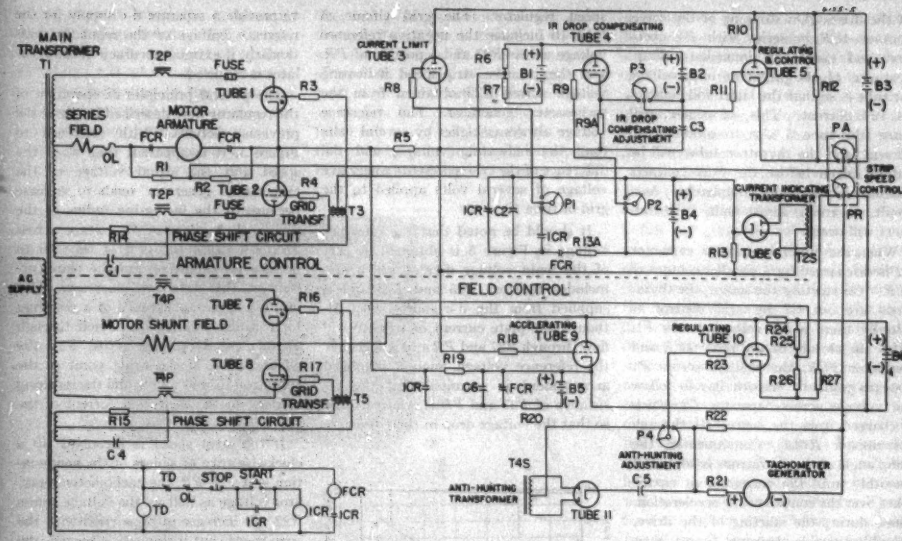

Figure 5. Schematic diagram of the electronic drive for windup reels

normally drooping characteristic of about 10 per cent will mean a very poor speed regulation and even the inability of the drive to develop full torque.

In order to correct this objectionable droop, an *IR* drop compensating circuit is provided. The main element of the compensating circuit is tube 4, which is controlled automatically by a grid voltage proportional to the armature current. The indication of the latter is obtained through a special current transformer *T2* whose two primary current windings *T2P* are connected in series with the anodes of the power thyratrons 1 and 2. Although each of the windings conducts unidirectional current pulses, connections are such that the resultant magnetic effect is the same as if an alternating current were flowing in the current windings. This prevents the saturation of the current transformer. The voltage generated in the voltage winding *T2S*, generally speaking, is proportional to the motor current. This voltage is rectified by means of tube 6 and then filtered out (the filter is not shown in Figure 5) so that the direct voltage across *R*13 may be used as an indication of the armature current.

There are two main voltage components in the grid circuit of tube 4: the negative bias voltage obtained from *P*2, necessary to determine the proper operating point of tube 4, and the positive current-indicating voltage, described in the preceding paragraph. Thus, an increase in motor torque and motor armature current will cause an increase in plate current of tube 4 and an increase in magnitude of the voltage across *P*3. It will be noted that *P*3, which represents the *IR* drop compensating adjustment, forms part of the grid circuit of the master control tube 5. The voltage across the adjustable portion of *P*3 forms an additional negative component of the grid voltage of tube 5, and with increasing load current of the motor, the grid of tube 5 becomes more negative, the plate current decreases, and the firing point of the power thyratrons is advanced just enough to compensate for increasing *IR* drop of the motor. Conversely, the opposite will occur with decreasing load of the motor.

Tube 3 acts as a current-limiting element of the armature control system. This tube, which is characterized by a sharp cut-off, is biased off by an adjustable negative voltage obtained from *P*1 and does not conduct any current for all the normal loads of the motor. However, when the load current of the motor exceeds a certain critical value, the voltage across *R*13 becomes so high that tube 3 will start to conduct. It will be noted that the load resistor of tube 3 designated as *R*5 is in the grid circuit of the master control tube 5. As soon as tube 3 starts to conduct, a voltage appears across the resistor *R*5, and the polarity of this voltage is positive with respect to the grid of tube 5. Since tube 3 itself provides a considerable amplification, a very small increase of the voltage across *R*13 beyond its critical value results in appearance of a much higher voltage across *R*5. As a result, the plate current of tube 5 is increased, the firing point of the thyratrons delayed, and the armature voltage lowered.

If the motor current continues to rise, the delay of firing point of the rectifiers will soon become so great and the armature voltage so low that the motor will stall with the armature current reaching its limit value. This limit is normally of the order of 200 per cent of the motor rated current, although it may be adjusted by means of the potentiometer *P*1. The current limit which, for a given excitation of the motor, may be called torque limit, plays an obviously important part during the acceleration and overload of the drive.

Capacitor *C*2 connected in parallel with the current limit control potentiometer *P*1, as well as contacts 1*CR* and *FCR* in series with *P*1, have an important function during the starting and stopping

of the drive. On stopping of the drive, contact 1*CR* in series with *P*1 opens first and causes an immediate disappearance of the negative bias voltage for tube 3, so that the latter will conduct its full current. This, of course, will cause the tube 5 also to conduct full current, and the thyratron tubes will be cut off, even before the *FCR* contacts will have time to open completely. As a result, no arcing across main *FCR* contacts will occur.

When the motor is stopped, capacitor *C*2 is discharged by a parallel contact of 1*CR*. On starting the motor, the thyratrons are cut off by grid control as initially there is no voltage across *P*1. After the closure of the relay 1*CR* and contactor *FCR*, the voltage across *P*1 appears gradually since it has to follow the voltage across capacitor *C*2 which is charged from the source *B*4 through the resistor *R*13*A*. Consequently, the firing angle of the thyratrons is advanced smoothly until the current limit circuit takes over the control of the acceleration. Thus, during the starting of the drive, no objectionable current surges may occur in thyratrons 1 and 2, and no sparking on the main contacts of *FCR* ever takes place.

Field Control Circuits

A general outline of the strip speed regulator operating through the field control of the motor was given in one of the previous sections of the paper. A simplified schematic diagram of the strip speed regulating system is shown in Figure 5. It must be noted that the power rectifier portion of the electronic field exciter is fundamentally the same as the power rectifier for armature control, described in the previous section. It consists of two thyratron rectifiers 7 and 8, a center-tapped transformer winding, a grid transformer *T*5, and a phase-shift circuit which provides the constant a c component of the thyratron grid voltage. The current transformer *T*4, however, has a function different from that of transformer *T*2.

The variable d-c component of the thyratron grid voltage is developed between the cathodes of the thyratrons and the center tap of the grid transformer. It consists of two voltages: a constant negative voltage across *R*25 and a variable positive voltage across *R*24. The voltage across resistor *R*24 is changing with the plate current of either tube 10 or 9, or both.

Tube 10 is the field regulating tube and represents the amplifier of the strip speed regulator. The grid circuit of tube 10 includes the negative reference voltage across *R*27 and a portion of *PR*, and the positive strip-speed indicating voltage across *R*22 obtained from the tachometer generator. The reference voltage always is higher by several volts than the indicating voltage, and the difference of the two represents a negative voltage of several volts applied to the grid of tube 10.

It should be noted that the reference voltage in Figure 5 is obtained as part of the main voltage divider which also includes resistors *R*25 and *R*26 and is supplied from the d-c source *B*6. Although the plate current of tube 10 will flow through *R*27 and *PR* and will change the reference voltage, such a simplified arrangement is permissible if the resistance of *R*27 and *PR* is relatively low so that the voltage drop in these resistive

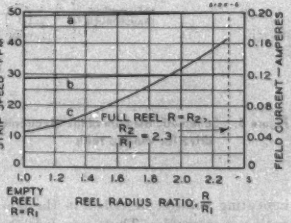

Figure 6. Typical operating characteristics of the electronic drive

elements caused by the plate current of tube 10 is small. Furthermore, one must remember that during the operation of the regulator the plate current of tube 10 changes only slightly because of the general amplification of the system, so that the actual change in reference voltage caused by the change in plate current of tube 10 is negligible.

As an example, with total reference voltage of 25 volts, the resistance of *R*27 and *PR* equal to 1,000 ohms and the change in the operating plate current of tube 10 of 0.1 milliampere for the entire reel-diameter build-up of two to one, the resulting change in reference voltage will be equal to 0.1 of one volt. Thus, the error caused by the change in the reference voltage will amount to 0.4 of one per cent.

Although the figures cited in the previous paragraph are based on actual test records, they may vary for different motors and different reel-diameter ratios, and in some cases it may be advisable to provide a separate d-c supply for the reference voltage of the regulator, particularly if extreme accuracy of the regulator is required.

The general principles of operation of the regulator were described in one of the previous sections. With reference to Figure 5, it is apparent that when the speed and the signal voltage of the tachometer generator tends to increase because of the increasing radius of the reel, a slight increase in voltage across *R*22 will cause the grid of tube 10 to become less negative, and the plate current of this tube will increase. This will cause the appearance of a restoring force which will manifest itself through an increase in voltage across *R*24, the advancement of the firing point of the thyratron tubes 7 and 8, and the resulting increase in the excitation current of the reel motor.

If the strip speed is increased by a clockwise turn of sliders of the combination unit *PA–PR*, the tachometer generator voltage as well as the voltage across *R*22 will increase in proportion with the strip speed, but if properly adjusted, the reference voltage across the active portion of *PR* will increase likewise. In that manner, the difference of the two voltages in the grid circuit of tube 10 will remain the same and the field current of the reel motor will not change.

Under normal operating conditions, during the regulating process, the accelerating tube 9 does not conduct any current being biased off by the negative grid voltage across *R*19. It will be noticed that in addition to resistor *R*19 the grid circuit of the accelerating tube 9 also includes the resistor *R*5 whose significance in the armature control circuits was described previously. This resistor, however, plays a very important part in the field control circuits as well.

Before the drive is started the relay 1*CR* is de-energized, and there is no voltage across the resistor *R*19. Consequently, the accelerating tube 9 conducts full current resulting in full voltage across *R*24 and full exciting current of the reel motor. After the start pushbutton is depressed both 1*CR* and *FCR* pick up and the negative bias of tube 9 gradually appears across the resistor *R*19. The increase of the voltage across *R*19 is gradual because of the charging of capacitor *C*6 through resistor *R*20. As a result, the plate current of tube 9 and the voltage across *R*24 will decrease slowly and so will the excitation current of the motor. In the meantime, however, the motor and the tachometer generator will continue to accelerate, so that at a

certain moment when the tachometer generator voltage becomes high enough, the regulating tube will start to conduct current and will take over the control of the motor excitation in the manner as described previously. If, however, the motor does not have enough time to accelerate to its operating speed before the capacitor $C6$ is charged completely, the presence of the positive voltage across $R5$ will prevent both the plate current of tube 9 and the field current of the motor to decrease below a certain minimum value, so that an adequate accelerating torque will be maintained. As soon as the acceleration of the reel system is completed, the armature current will drop to a normal operating value, the voltage across $R5$ will disappear, and, if the charging of capacitor $C6$ was completed before, the plate current of tube 9 will disappear also.

The antihunting circuit of the regulator consists of transformer $T4$, tube 11, capacitor $C5$ and potentiometer $P4$. Transformer $T4$ is basically of the same type as transformer $T2$ which was described previously. The voltage obtained in winding $T4S$ of this transformer is rectified by means of tube 11, but the d-c component of the rectified voltage does not appear across $P4$, being blocked by capacitor $C5$. However, if the field current will tend to change abruptly, a transient current caused by charging or discharging of capacitor $C5$ will flow through $P4$. Thus, a transient voltage will appear across $P4$ and this voltage always will be of such polarity with respect to the grid of tube 10 that an action opposing a fast change in the restoring force will occur. It should be noted that this damping action will take place in response to the rate of change of the average field current and not to the change itself. Thus, if the average field current tends to increase abruptly, a high charging current of capacitor $C5$ will cause the appearance of a transient negative voltage in the grid circuit of tube 10. This voltage will tend to decrease the plate current of the regulating tube, and, consequently, oppose the previously mentioned rise of the field current.

Figure 7. Main elements of a 3-horsepower drive for windup reels

Performance and Conclusions

Typical operating characteristics of the electronic drive are shown in Figure 6. They represent the strip speed in feet per minute as a function of the reel-radius ratio for two different strip speed settings.

The corresponding change in the field current of a 3/4-horsepower reel motor is also shown in Figure 6.

It will be noted that in the particular case represented in Figure 6 the radius of the reel increased 2.3 times during the entire reeling operation. Theoretically, if a constant speed motor were used (an induction motor for example) the strip speed during the reeling would increase in proportion, that is, the speed at the end of the reeling operation would constitute 230 per cent of the speed at the start of reeling.

With the electronic drive the strip speed changed from 48.8 feet per minute for empty reel to 50.0 feet per minute for a full reel, that is, increased by 2.46 per cent. The accuracy of the regulator is related closely to the general stability of the whole system and depends upon the type of the motor, the reel-diameter ratio, the behavior of the back-tension during the reeling operation and other similar factors. For many systems of the more stable character, the accuracy of regulation can be easily improved to one or even one-half of one per cent at full strip speed. For lower strip speeds the amplification of the system will be lower, and the percentage of regulation will be increased correspondingly. Thus, for a strip speed set at 30 feet per minute (see Figure 6), the speed will change from 28.8 feet per minute to 30.0 feet per minute or by 4.16 per cent.

An important condition for a satisfactory operation of the drive is the selection of a proper operating range of the motor field current. The portion of the motor magnetic characteristic which represents the range of appreciable saturation should not be used, since over that range the overall amplification of the system is reduced considerably. It may be noticed from the field current graph in Figure 6 that the range of high saturation of the motor has been left outside the operating range of the system. In other words, if the motor is designed so that its full field current corresponds to an appreciable saturation of its magnetic characteristic, the operating full field current should be sufficiently below the rated full field current of the motor.

A typical 3-horsepower electronic drive for a windup reel is shown in Figure 7. It includes the complete electronic rectifier and control system enclosed in the cabinet, the reel motor, the tachometer generator and the operator's control stations. In addition to the parts shown in Figure 7, a complete system also includes a power transformer, not shown in the figure.

Reference

1. Electronic Control of D-C Motors, K. P. Puchlowski. AIEE Transactions, volume 62, 1943, pages 870–7.

Protection of Industrial Plants Against Insulation Breakdown and Consequential Damages

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Synopsis: Experience has shown that multiple electrical failures may occur simultaneously in an industrial plant as the result of an initial breakdown of insulation causing high transient voltages. Available methods of surge protection to guard against insulation breakdown and neutral grounding to prevent high transient voltages are presented. Consideration is given to the merits and limitations of these methods when applied to industrial plants.

PROTECTION against insulation breakdown and its consequential damages long since has been considered paramount by utility engineers. Their experiences in supplying dependable power at low cost have proved that in the electrical industry there is much wisdom in the old adage, "An ounce of prevention is worth a pound of cure." As industrial plants become more and more electrified, and they are doing so rapidly, industrial engineers likewise must pay more heed to this very important problem. It is the purpose of this paper, therefore, to review some of the factors involved and to outline modern methods of protection that have proved beneficial in industrial plants.

Fundamental Considerations

Electricity under control is mankind's most submissive form of power and functions with almost magic imperceptibility. However, it is ever on the alert to escape its fetters and, once on the loose, it becomes a violently destructive force that defies submission. It is imperative, therefore, that great care be taken to keep it under control, that its path of destruction be limited in case it gets out of control, and that it be brought back under control as quickly as possible. In the language of the protection engineer, these fundamental requirements are:

1. Guard against insulation breakdown or flashover by adequate surge protection.
2. Prevent high transient voltages or severe burning as a result of insulation failure by proper neutral grounding.
3. Clear faults rapidly by fast and well-co-ordinated relaying.

It is intended that this paper deal mainly with the first two requirements.

Protection Against Insulation Breakdown

The insulation of a circuit or piece of apparatus will withstand safely the normal operating voltage for which it is intended unless it has become defective as a result of moisture, overheating, or mechanical damage. Trouble from these causes can be minimized by proper maintenance, careful handling, and periodic maintenance. However, it is not practical to build enough insulation into distribution circuits or apparatus windings to withstand surge voltages to which they may be subjected. Protection against these surges, therefore, must be provided commensurate with the severity of surges to be expected and the type of insulation involved.

Industrial plants that receive their power from distant sources usually are supplied over one or more high voltage circuits, 33 kv or higher, into transformers that step down the voltage to 13.8 kv or less for distribution in the plant. If the source is close by or within the plant, power generally is supplied directly at distribution voltage. The circuits may be underground, overhead, or a combination of the two. If they are entirely underground they are free from lightning and require no surge protection. If overhead and exposed, they are subject to lightning surges that may flash them over, break down the insulation of apparatus connected to them, or both. Where combination overhead and underground is used, it is possible for dangerous surge voltages to build up at the junction points between the overhead and underground circuits. Surge voltages also may pass on into the cable and reflect to high values at the far end. The type of circuits and methods of apparatus connection, therefore, have a direct bearing upon the overall scheme of protection which should include protection against both line flashover and breakdown of apparatus insulation.

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Line Flashover

Overhead lines can be insulated and shielded to be practically free from lightning flashover.[1] While this commonly is done with high voltage circuits, 69 kv and above, where the insulation and clearances are inherently high, it usually is not considered practical for the lower voltages because of the extra insulation and conductor spacings required. There are exceptions, however, where shielding of low voltage lines can be justified to provide protection to important apparatus connected to the line. Such circuits often are shielded partially by near-by buildings, trees, and so forth.

Low voltage lines, 13.8 kv and below, may flashover from induced surges as well as direct strokes. If wood construction is used as it generally is, some of these flashovers do not result in trip-outs, although many do.

It is quite common practice to minimize the disturbance caused by trip-outs by

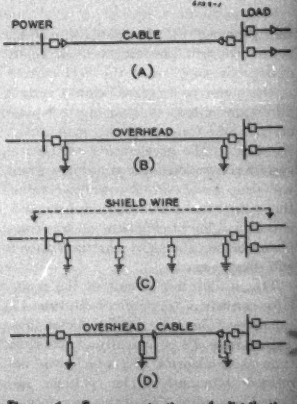

Figure 1. Surge protection of distribution circuits

A—All cable, no protection required
B—Overhead, terminal protection only
C—Overhead, lightningproof protection by either shield wire or spaced lightning arresters
D—Combination overhead, underground. Arresters not required at load end if cable length is less than 100 feet

rapid reclosing of the feeder breaker. In some cases, where trip-outs are extremely undesirable, line flashovers can be prevented by spacing line-type lightning arresters along the line at 500- to 1,000-foot intervals.

Lightning arresters should be provided at junctions between overhead and underground circuits to protect against high voltages at those points caused by reflected traveling waves. The arresters should be connected directly between the conductors and the cable sheath, and grounded. If the cable is over 100 feet in length, arresters also should be provided at the far end, particularly if the cable feeds into an exposed line or has important apparatus with low surge strength, such as rotating machines, connected to it.

The recommended methods of protecting the different types of distribution circuits that might be involved in an industrial plant are shown schematically in Figure 1.

Apparatus Protection

There are two general classes of electric apparatus that must be considered in the over-all scheme of protecting an industrial plant. One of these includes that equipment, such as oil-insulated transformers, that has surge strengths equivalent to basic insulation levels that have been established for the different voltage classifications.[2] This class of equipment can be protected adequately by standard lightning arresters of the proper voltage rating connected between the exposed line leads and ground. The arresters should be located as close as possible to the apparatus frame or tank as shown in Figure 2.

The second class includes apparatus such as air-cooled transformers and rotating machines that have impulse levels

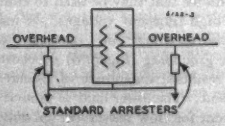

Figure 2. Surge protection of apparatus meeting basic insulation levels

lower than the basic insulation levels. A comparison of the impulse levels of oil-insulated and air-cooled transformers from 1.2 kv to 15 kv classification is given in Table I. The surge strength of rotating machines are normally somewhat less than the values shown for air-cooled transformers. Because of its lower impulse level,

Table I. Comparison of Impulse Insulation Levels

Insulation Class (Kv)	Impulse Levels 1½x40 μsec Wave Kv Crest: Oil-Insulated Transformer	Impulse Levels 1½x40 μsec Wave Kv Crest: Dry-Type Transformer (Proposed)
1.2	30	10
2.5	45	20
5.0	60	25
8.66	75	35
15.0	95	50

this second class of apparatus requires special protection, particularly when connected directly to overhead lines that are exposed to lightning surges.

Air-cooled transformers that are subject to surge voltages should be protected by special arresters, similar to those used for rotating machine protection, at the

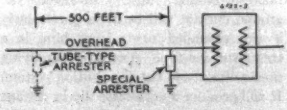

Figure 3. Surge protection of dry-type transformers

transformer terminals,[6] (Figure 3). If the transformer is connected directly to an overhead line, a set of standard arresters, either valve or tube type, also should be connected about 500 feet ahead of the transformer. Tube-type arresters are influenced somewhat less by arrester ground resistance. Liquid-filled transformers should be used in preference to air-cooled transformers where the circuit is exposed highly to severe surges.

Recommended methods of protecting rotating machines are given in a paper by by McCann, Beck, and Finzi.[5] The essential requirements are to limit the magnitude of surge voltage at the machine terminals to protect the insulation to ground, and to slope the front of the surge wave so that it will not pile up across a few turns of the machine winding and overstress the turn-to-turn insulation. The first of these requirements is accomplished by special lightning arresters having low sparkover characteristics, and the second by shunt capacitors and series inductance. These fundamental components of the protective scheme are illustrated in Figure 4*A*. Actually, the series inductance may be a section of the incoming line, 500 feet in length, immediately ahead of the machine (see Figure 4*B*). A standard line-type arrester is required ahead of the series inductance to limit the magnitude of surge voltage that can pass in to the inductance and shunt capacitor combination. This arrester preferably should be a tube type if the ground resistance is more than two or three ohms, because the discharge voltage across the tube collapses to near zero for a half cycle, thus resulting in only a small amount of surge energy being transmitted into the protective devices at the machine terminals. Where the line is exposed to severe surges, or where the arrester ground resistance is higher than about five ohms, one or more additional sets of arresters should be placed out on the line at about 500-foot spacings. The first 500-foot line section ahead of the machine should be shielded (see Figure 4*C*) if there is danger of a direct stroke of lightning in that section.

The special arresters at the machine terminals should be valve type because of its lower sparkover voltage. The best protection is provided by station-type arresters which are recommended where the kilovolt-ampere rating of the machine or machines protected exceeds 1,000. The special line type generally is considered adequate for smaller sized machines.

Where several rotating machines are connected to a common bus, adequate protection can be provided by means of a single set of special arresters and capacitors connected to the bus, if each machine

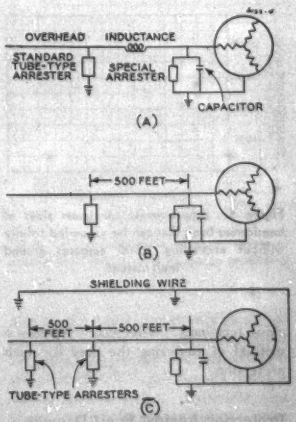

Figure 4. Surge protection of rotating machines

A—Fundamental scheme
B—Equivalent scheme
C—Protection against severe surges including line shielding and spaced lightning arresters

is connected to the bus by an unexposed circuit not over 200 feet in length. Otherwise, each machine should be provided with a set of capacitors and special arresters mounted near its terminals. If there is enough cable connected to the bus (see Table II) to provide the required shunt capacitance, no capacitors are necessary.

In some industrial plants, there may be individual motor loads, such as pump motors, tapped off a common overhead circuit at intervals along the line. For the best protection to all the motors the line should be shielded against direct strokes and special rotating machine protection provided at each motor. If shielding is not feasible, each motor should be provided with a series choke coil, special valve-type arresters and wave sloping capacitors at the motor terminals, and a standard line-type arrester ahead of the choke coil.

Rotating machines connected to the secondary windings of transformers whose primary windings are connected to overhead lines may not need rotating machine protection if the primary winding of the transformer is protected adequately. However, if large or important machines are involved, and are located close to the transformer, the risk of failure from surges passing through the transformer justifies the provision of special arresters and wave sloping capacitors at the machine terminals. Reference 5 includes a method of analyzing the need for such protection.

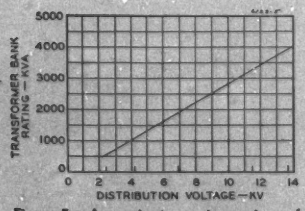

Figure 5. Approximate maximum sizes of transformer bank that can be grounded solidly without exceeding 2,500 amperes ground fault current

Protection Against Fault Damage

Even with good maintenance and surge protection there will be occasional faults, most of which will start as short circuits between one phase and ground. Such a fault may result in considerable damage by causing either severe arcing or high transient voltages, depending on whether the system neutral is grounded, and if so, how.[7-18]

Table II. Surge Capacitors or Equivalent Length of Cable Required for Rotating Machine Protection

Machine Voltage Class (Kv)	Capacitance Per Phase (Microfarad)	Cable Voltage Class (Kv)	Length of Cable (Thousands of Feet)			
			00	250,000 Cir. Mils	500,000 Cir. Mils	750,000 Cir. Mils
2.4	0.5	2–3	35	25	20	15
4.16	0.5	4–5	45	30	25	20
6.9	0.5	7–8	50	35	25	20
13.8 (grounded)	0.25	14–15	30	25	20	15
13.8 (ungrounded)	0.5	14–15	60	50	40	30

Neutral Point Available

If the neutral of the source of power to the distribution system, either generator or transformer bank, is grounded solidly, there will be no transient voltages of dangerous magnitude produced by a phase-to-ground fault. However, the ground current will be high, particularly if the grounded neutral machine is a steam-turbine-type generator supplying power directly to the distribution system. It will produce a noticeable dip in voltage and result in severe burning at the fault, unless the fault is cleared rapidly. It also may distort the windings of the grounded neutral generator which normally is designed to withstand short-circuit current no greater in magnitude than that resulting from a 3-phase short-circuit. The line-to-ground short-circuit current from a solidly grounded neutral generator usually will be greater than the 3-phase value.

If the source of distribution power is a transformer bank supplied from a high voltage line, grounding the neutral solidly will prevent dangerously high transient voltages resulting from ground faults. The magnitude of ground fault current will depend on the distribution voltage and the size of the bank. It will not cause excessive arc burning with moderate speed relaying if it does not exceed about 2,500 amperes. The approximate maximum sizes of transformer bank that can be grounded solidly without exceeding 2,500 amperes ground current are given in Figure 5. Higher ground currents are permissible if high speed relaying is provided.

If the neutral of the supply source is left ungrounded there will be no fault current when one phase becomes grounded except a few amperes of charging current through the circuit capacitance to ground. The extinction and restriking of this charging current may cause transient voltages between the unfaulted phases and ground high enough to destroy protective devices or to break down equipment insulation, thus causing one or both of the other phases to become grounded. A compromise between the high ground current and no transient voltages on the one hand and the high transient voltages and no ground current on the other hand is usually the best practical solution.

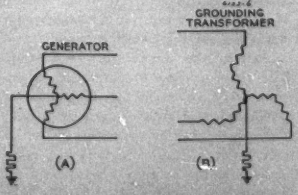

Figure 6. Low resistance neutral grounding

A—Generator neutral resistor
B—Grounding transformer with neutral resistor

Neutral Impedance

The magnitude of ground fault current can be reduced by inserting impedance in the neutral ground circuit. However, care must be exercised in fixing the make-up of this impedance. If it is resistance only, there is a wide range in the value of resistance that may be used to eliminate the high transient voltages. It may be classed as either "low" or "high" resistance grounding (Figure 6) depending on the resultant magnitude of ground fault current. The lower limit of ground fault current for "low resistance" grounding is the minimum value that will assure dependable relaying with ground relays, about rated full load current with minimum generating capacity. The upper limit is dictated by the amount of energy that can be dissipated in the resistor during fault, both from the standpoint of practical resistor size and shock to the supply generators. A reasonable value to use for the upper limit is 150 per cent of the rated load current of the minimum generating capacity, or 2,500 amperes,

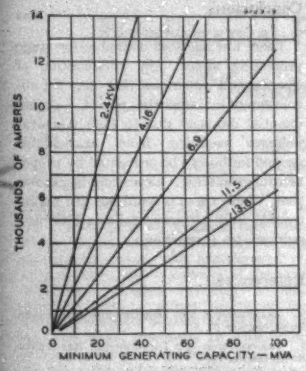

Figure 7. Approximate maximum values of ground fault current with neutral resistor grounding

whichever is the smaller. It usually will be desirable to approach this upper limit to assure prompt operation of ground relays under maximum fault resistance conditions. The curves of Figure 7 show values of ground fault current limited to 150 per cent of rated full load current for the voltages commonly used in industrial plant distribution systems. The minimum value of neutral resistance in ohms that should be used is equal to the line-to-neutral voltage divided by the value of fault current given by the curves.

From the standpoint of limiting the transient voltages, it is only necessary to use a neutral resistor of low enough resistance to dissipate energy equal in kilowatts to the charging kilovolt-amperes supplied the system at the time of a ground fault. This depends upon the maximum amount of circuit, particularly cable circuit, and the number and size of machines connected at any one time. With this value of neutral resistance, classed as "high" resistance, the current in the fault would be only about 50 per cent more than the charging current which would be but a few amperes at the most. The faulted circuit, therefore, could be left in service without danger from transient voltages or arc burning until convenient to remove it. In practice, an alarm actuated from a voltage relay connected to measure voltage between neutral and ground would be used to indicate when a grounded conductor existed. The circuit relaying, initially set up on the basis of ungrounded neutral service, would not be affected.

The effect of such a high resistance, neutral ground (Figure 8), can be provided more practically for 2,300 volts and higher by using a standard distribution transformer with a low voltage resistor connected across its secondary winding. The primary winding should have a voltage rating equal to the circuit voltage. It should be connected between the generator neutral and ground. The secondary winding may be 120, 240, or 480 volts, depending on the rating of the most applicable resistor which should be chosen to dissipate power during a line-to-ground fault equal in kilowatts to at least the maximum charging kilovolt-amperes drawn by the system during a ground fault. A voltage relay generally is connected across the resistor to serve as a fault detector.

When resistance grounding is used, the system neutral becomes displaced almost fully during a ground fault. This requires that lightning arresters connected to the system have a voltage rating not less than line-to-line voltage as is necessary with ungrounded neutral operation.

If the neutral impedance is reactance (Figure 9) there is a limit to how far the ground fault current can be reduced without causing high transient voltages. To be safe, this minimum value should not be less than about 50 per cent of the magnitude of the 3-phase fault current. The curves in Figure 10 show the minimum safe ground fault currents with reactance grounding for the different distribution voltages.

A combination reactor and resistor in parallel will permit high transient voltages unless the resistance is low compared to the reactance. Therefore, the two in parallel offer very little, if any, advantage over a resistor only.

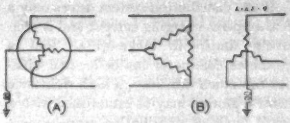

Figure 9. Reactance grounding

A—Generator neutral reactor
B—Transformer with or without neutral reactor

Any neutral ground scheme that permits enough ground fault current to cause arc damage requires ground relays. If the neutral is grounded solidly, the ground fault current would in most cases be high enough to operate phase relays. However, there may be occasional high resistance ground faults that would not draw enough current to operate phase relays in which case considerable damage from burning might result if ground relays were not provided.

Neutral Point Not Available

Many industrial plant distribution systems do not have a neutral point available for grounding, particularly those that operate at 2,300 or 6,900 volts, delta. As previously pointed out, such systems are conducive to high transient voltages during ground faults. Experience has shown that a failure of a machine winding or cable circuit to ground often results in the simultaneous failure of other machines or cables. The remedy is to supply one or more supplementary neutral grounds to assure that all feeder sources are grounded adequately at all times.

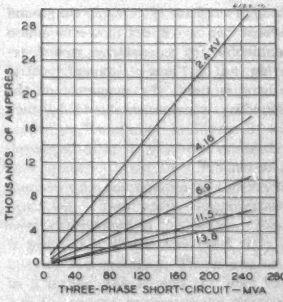

Figure 10. Approximate minimum values of ground fault current with reactance grounding

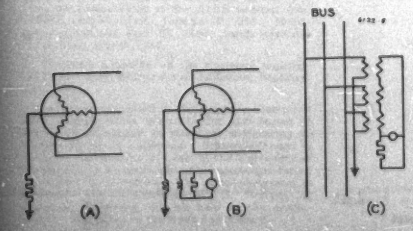

Figure 8. High resistance neutral grounding

A—Generator neutral resistor
B—Distribution transformer in generator neutral with secondary resistor
C—Bank of distribution transformers with secondary resistor

If the distribution system draws only a few amperes charging current and is relatively simple in make-up so that a grounded conductor can be located without too much difficulty, a high resistance neutral ground may be established with a small bank of distribution transformers and secondary resistor as shown in Figure 8*C*. The star-connected primary windings should be connected to the distribution bus with neutral grounded. The resistor should be connected inside the delta of the low voltage winding. The resistance should be chosen to dissipate energy equal in kilowatts to at least the charging kilovolt-amperes of the system during a ground fault. This scheme of grounding is similar to the distribution transformer–secondary resistance scheme described previously, in that it serves only to limit the transient voltages and to indicate a ground fault. The fault current is too low to cause arc burning so that ground relays are not necessary.

The other method of providing a supplemental neutral ground is to use a grounding transformer, either zig-zag or star delta connected with the neutral grounded. If grounded solidly it is classified as reactance grounding and carries the same limitation as described previously, that is, that the ground current should not be less than about 50 per cent of the 3-phase fault current. If grounded through a resistor (Figure 6*B*) the ground current can be reduced to the minimum permissible for satisfactory ground relaying. If a "low resistance" neutral resistor is used, the reactance of the grounding transformer should be such that if the transformer were grounded solidly, the ground fault current would not be less than about 50 per cent of the 3-phase value. Relays that will clear ground faults promptly are necessary to prevent excessive arc burning.

Preferred Method of Neutral Grounding

The essential requirement of a neutral ground is that it will suppress high transient voltages during ground faults. The scheme best suited to any particular industrial plant depends on a number of factors, such as the surge protection required, the magnitude of the power source, whether a neutral point is available or not, the number and complexity of circuits involved, and the type of relaying that is or can be provided. From the standpoint of surge protection, either solid neutral or reactance grounding that limits the ground fault current to not less than 60 per cent of the 3-phase fault current is preferable, because either one makes it possible to apply reduced rating (80 per cent) arresters. If the insulation is questionable, this may be the deciding factor. However, either of these types of grounding produces high ground fault currents if the distribution system is supplied at generator voltage and the generating capacity is large. When those conditions exist, resistance grounding generally will be suited better. The distribution transformer–secondary resistor scheme often works out advantageously where the distribution system is not too complex and where it is not feasible to add ground relays.

Conclusions

There are methods available for surge protecting almost any combination of circuits and apparatus that may be encountered in industrial plants. Consequential damages due to high transient voltages resulting from unavoidable ground faults can be prevented by proper neutral grounding. Experience has shown that, where these precautions are taken, trouble from electrical failures has been reduced to a minimum.

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Fundamental Properties of the Vacuum Switch

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Synopsis: The main results of a study of the various phenomena which take place during the interruption of currents in high vacuum are given. The experimental results obtained lead to a theory of the basic mechanism affecting switching in high vacuum. With a proper design of the switch, a constant working pressure can be obtained which represents an equilibrium between gases and vapors evolving from the electrodes and a pumping action based on the sputtering of cathode material. A detailed study is made of the factors determining the loss of electrode material because of switching. The most essential design features of a vacuum switch are discussed briefly.

SWITCHING is one of the most frequently performed operations in electrical circuits. Even though switching plays a very important role, the equipment performing this operation, the switches and circuit breakers, have by no means reached the last degree of perfection.

No satisfactory d-c breaker has been developed yet for the interruption of medium or heavy loads at high voltage.

The interruption of alternating current is made much easier by the periodical occurrence of the current zero which represents a natural means of deionization. The difficulty here lies in the fact that severe requirements are made with respect to the time of interruption.

System stability studies indicate that faults on transmission lines, particularly of large interconnected systems, should be cleared in a minimum of time. This is the main reason why the increase in load of the past 15 years gradually has placed stronger requirements on the opening time of breakers. Whereas in 1930 a 10- to 15-cycle breaker was found to be satisfactory, today the tendency is to clean faults in three cycles. It is to be expected that in the near future still more severe specifications will have to be made on the interruption time.

In some cases no restrikes after the first current zero are permissible, as for example in the interruption of charging current. Restrikes would result in high overvoltages, exceeding the normal line voltage several times.[1,2] This is particularly dangerous on power lines where sections of cable are incorporated.

With the present designs of circuit breakers, it is very difficult to meet requirements of the type mentioned above. The main difficulty encountered by the present methods of arc extinction lies in the small dielectric strength of the interrupting medium. The rate of recovery of dielectric strength is small, even when large opening speeds are used.

It was recognized early that the use of high vacuum as an interrupting medium is expected to have two features which are of great importance for the rapid interruption of currents:

1. The dielectric strength of high vacuum[3,4,5] is greater by far than that of any other interrupting medium in use.

2. Once an arc has been formed in a high vacuum, a fast radial diffusion of the current carrying particles takes place and provides a most ideal means of deionization.

A great deal of research and development has been done on vacuum switches. In 1921 the first small vacuum switch was built commercially by the Swedish Birka Company.[6] From 1923 to 1926, Sorensen and Mendenhall[7] performed extensive tests with larger vacuum switches at the California Institute of Technology. Around 1932 interesting investigations were carried out by Seitz[8] and Jubitz[9] in Germany.

As a result of these efforts, excellent small current capacity vacuum switches are commercially available and are finding a steadily increasing field of application.

Today, however, the vacuum switch is not able to compete in power circuits. No explanation for this fact can be found in the literature. There is also no theory given explaining the various processes affecting the interruption in high vacuum.

The aim of the investigation described in this paper was to clarify some of the important and basic points involved in this problem.

Experimental Setup

The investigation was carried out entirely on direct current. The interruption of alternating current only would have complicated the analysis greatly without giving any new information about the basic mechanism of the interruption.

The two switches shown in Figures 1 and 2 were built for this study. The switch of Figure 1 is completely glass-sealed, allowing studies to be made at very low pressures of 10^{-6} millimeter of mercury or less. This switch is actuated magnetically by means of a nickel plunger and a trip coil. The second switch, shown in Figure 2, was developed after it had been established that pressures below 10^{-4} millimeters of mercury were not required for a successful operation. Two main improvements were incorporated in this switch. First, it provides a simple and quick way of opening and resealing. Picein was used as a sealing wax around the steel base and the ground bottom of the glass jar.

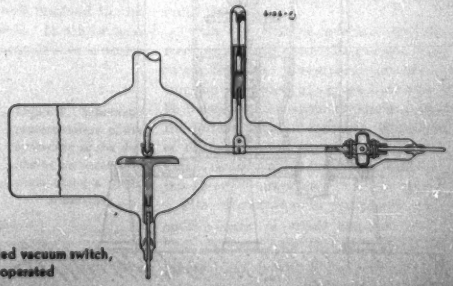

Figure 1. Glass-sealed vacuum switch, magnetically operated

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The second improvement consisted of an accurate and easily changeable speed of separation of the electrodes, which is a significant variable. A spring located in the socket of the lower electrode provided the desired contact pressure. When the switch was tripped, the lower electrode followed the parting upper electrode until a stop in the socket was reached. At this point the lower electrode was arrested and the electrodes separated.

The switch is actuated by an outside mechanism shown in Figure 3. The motion is transmitted to the switch by means of a metal bellows located at the top of the switch.

The disk D of Figure 3 is rotated at synchronous speed. The opening spring Sp is expanded by means of a pin A mounted eccentrically on the disk B. A short time before the maximum stretching of the spring is reached, the cam switch SW closes and energizes the coil and the magnet M. This locks the tripping toggle T by means of the latch L. The tripping coil TC releases the tripping toggle. This results in a rapid opening of the switch. The trip coil can be energized by closing the switch S or through the cam switch CS. This cam switch permits the automatic operation of the vacuum switch. This is important because thousands of operations are required to determine accurately the average loss of electrode material per interruption, which is very small.

The vacuum system used is illustrated by Figure 4. The vacuum is created by a forepump F and a 2-jet mercury diffusion pump J. Another forepump M was used to reduce the time required for the complete evacuation of the vessel. The use of this pump for the first part of the evacuation also helped greatly to keep the two liquid air traps clear of ice formation.

The pressure in the vessel was measured with a cold cathode ionization gauge I of the Penning[10] type. The McLeod gauge G was used for checking purposes only.

The speed of separation of the electrodes of the spring operated switch was measured with a mechanical speedograph.

Another method had to be devised for the measurement of the opening speed of the magnetically operated switch. There the force available from the magnetic plunger was too small for the use of a speedograph. An optical method illustrated in Figure 5 was used instead.

A narrow vertical beam of light is obtained by means of the condenser lens L_1 and the slit S. In the closed position of the switch, this parallel beam of light is obstructed completely by the electrodes. During the separation, a beam of light which is proportional to the width of the gap reaches the lens L_2 and is focussed on the phototube. The resulting phototube current then is amplified in order to give a satisfactory deflection on the screen of a cathode ray oscillograph.

A curve can thus be obtained on the screen, giving the separation of the electrodes as a function of time. Such curves used in conjunction with recovery voltage oscillograms allow one to determine the electrical field strengths present during interruption.

The Mechanism of Interruption

In what follows, a detailed analysis of the mechanism of interruption is given. This analysis is based on the various observations made by means of different methods, such as cathode ray oscillograms, fast movie films, microscopic studies of the electrode surface, and so forth.

At the beginning of the separation of the electrodes, the contact area is decreased rapidly. This results in a fast increase in current density, leading eventually to melting and evaporation of the electrode material. A vapor arc thus is created which rapidly blows itself out because of the rapid radial gaseous diffusion active in the evacuated space. The loss of current carriers because of this radial diffusion is large enough to disrupt quickly the self-sustaining discharge.

The average velocity of diffusion is given by[11] $C = \sqrt{4kT/m}$, where k = Boltzmann constant, T = absolute temperature, and m = mass of a gas molecule. At a temperature of a few thousand degrees Kelvin, the diffusion velocity is of the order of 10^5 centimeters per second, which is about 1,000 times greater than the speed of separation of the electrodes.

As soon as this first arc is blown out, a recovery voltage builds up across the gap, which is by now only about 10^{-}

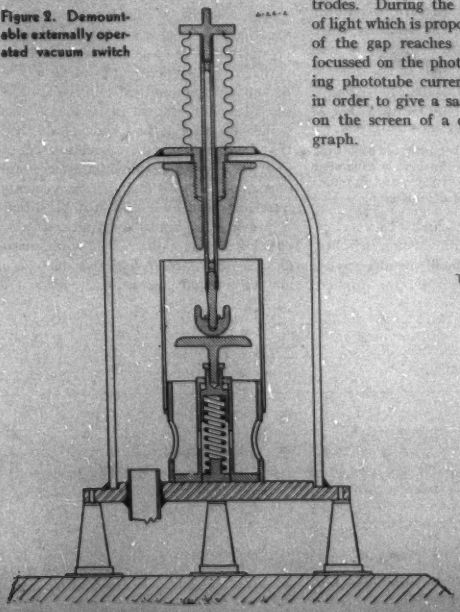


Figure 2. Demountable externally operated vacuum switch

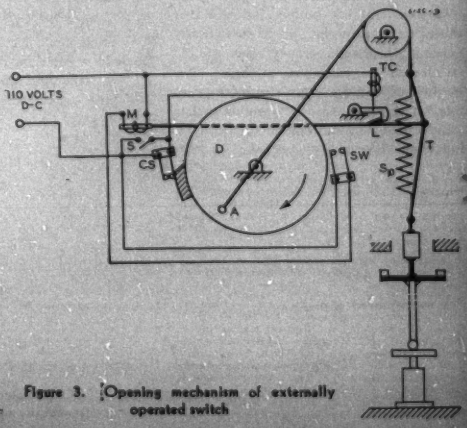


Figure 3. Opening mechanism of externally operated switch

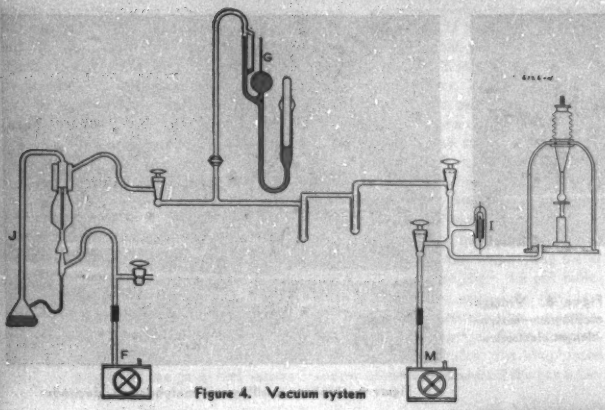


Figure 4. Vacuum system

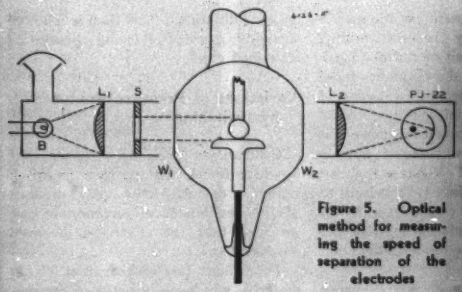


Figure 5. Optical method for measuring the speed of separation of the electrodes

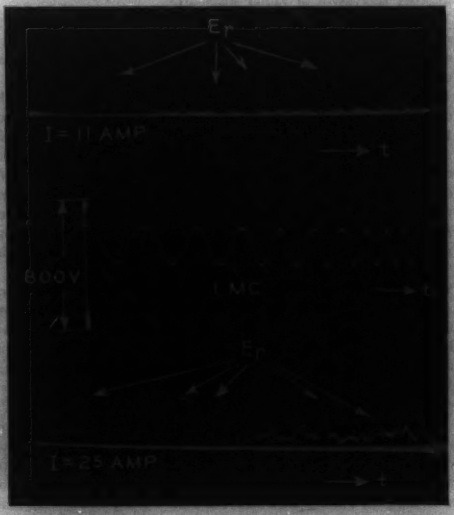


Figure 6. Voltage oscillograms with one megacycle timing wave—copper electrodes

of arc bursts of microsecond duration, interspersed with periods of extinction of even shorter duration. It is significant that the random character of this process is found by experiment not to be affected by the circuit constants.

For the case of a plate-cathode and a spherical anode, fast movie films show that the spark-arc mechanism moves away from the center of contact along a single radial line. This situation is represented schematically in Figure 7. It can be seen that the radial diffusion of the gas and vapors originated during each single arcing episode $A_1, A_2, A_3 \ldots$ creates ring-shaped zones of greatest gas vapor and ion density. The successive breakdowns $B_1, B_2, B_3 \ldots$ following the recovery voltages $E_1, E_2, E_3 \ldots$ take place in the regions where the ring-shaped

centimeters wide. Under this condition a relatively small recovery voltage creates a field strength of sufficient magnitude to break down the gap in the form of a special kind of spark arc mechanism to be discussed later. The initiating spark preferably will take place along a path where a small density of gas and vapors is left, that is, about one millimeter away from the former point of contact, owing to the diffusion in the microsecond of the first arc. The arc following the initiating spark is blown out again, and another recovery voltage E_r leading to a new breakdown builds up across the gap. Recovery voltages E_r of this type are well resolved in the oscillograms of Figure 6. It can be seen that the mechanism consists of a series zones overlap, that is, along a single radial line.

In the case of large currents, spark-arc mechanisms will occur along many separate radial lines. The separate arcs occurring simultaneously at a given time all will be located on a concentric circle around the former point of contact. This form of discharge along an arc of a circle is found to take place for currents exceeding about 30 amperes.

The interruption is completed when such a series of arcing episodes ceases. This happens once the path along the greatest gas density is too long, that is,

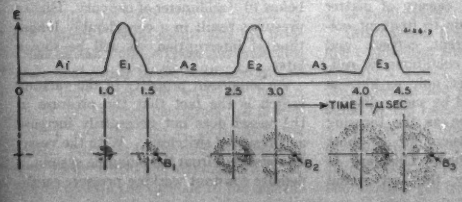


Figure 7. Schematic representation of the spreading of the discharge on a cathode plate along a single radial path

Center of the cathode plate

Figure 8. Voltage oscillogram—molybdenum electrodes

Figure 9. Voltage oscillogram—molybdenum electrodes

when its dielectric strength prevents a further breakdown. At the end of such a series of arcing episodes, the electrodes are still close together. If the circuit conditions create a high recovery voltage, the gap will break down near the center by field emission. This usually starts another succession of radial spark-arcs. Fast movie films were able to give evidence of repeated breakdowns near the center of the gap. The field strengths corresponding to such breakdowns exceed 10^4 volts per centimeter. It is therefore clear that this type of breakdown is initiated by field emission.[12]

Figure 8 shows a typical voltage oscillogram where a high recovery voltage occurred at point A, 3×10^{-6} second after the start of the interruption at point B. The total time of interruption (B to C) amounted to 3.2×10^{-4} second. The recovery voltage at point A was 552 volts, corresponding to a field strength of 2.76×10^4 volts per centimeter. The succeeding large recovery voltage which is clearly resolved occurred at point C and amounts to 1,380 volts, giving a field strength of 1.26×10^4 volts per centimeter. Large recovery voltages are always present at the end of the interruption of an inductive d-c circuit. The resulting field strengths are, however, no longer able to restrike. Figure 9 shows an interesting case where a field emission breakdown occurred at point A which was not able to reignite a new series of arcing episodes.

The fact that the mechanism of interruption is affected by field emission explains the observed great variations of the time of interruption. The determination of the statistical average time of interruption requires, therefore, the data of a large number of interruptions.

The study of electrode surfaces with the microscope revealed another interesting phase of the mechanism of interruption. Figure 10 shows the many microscopic craters of about 10^{-3} centimeter diameter which have been created on a tungsten cathode. The cathode also shows cracking and peeling of the surface which was caused by the heat resulting from the intense positive ion bombardment. The anode shows many fused spots; the rest of the surface is covered with sputtered material from the cathode. Carbon electrodes show even more distinctly the difference between cathode and anode surfaces. Figure 11 shows how the cathode surface is broken up to a great depth by the combined action of the positive ion bombardment and the explosive action of the suddenly liberated gas.

The anode has a smooth surface covered with sputtered carbon from the cathode. The microscopic craters observed on all cathodes reveal the presence of a focusing action. The conditions present during the periods of recovery voltage E_1, E_2, E_3... (see Figure 7) as well as during cold emission restrikes are leading to the conclusion that a magnetic self-focusing action of the Bennett[13] type takes place. This magnetic self-focusing concentrates the positive ion bombardment on small areas on the cathode, resulting in local fusion and evaporation. This creates microscopic craters of the type indicated by arrows in Figure 10. The self-focusing action lasts only about one microsecond. After this interval of time, the conducting streams are no longer self-focusing because the density of matter near the cathode leads to frequent collisions between current carriers and neutral atoms. The conditions for self-focusing hold, however, only as long as the energy loss caused by such collisions is negligible. As soon as the focusing action ceases, a transient arc of short duration is established. This arc is quickly deionized by the fast radial gaseous diffusion. This then is followed again by a series of arcing episodes as described earlier.

Variations of Pressure Produced by Switching

Contrary to previous statements, it has been found that the vacuum switch normally operates at a vessel-pressure of 10^{-4} millimeter of mercury or less, provided that the electrodes are well outgassed.

Throughout this investigation, stock-material was used for the electrodes. The outgassing or conditioning of such electrodes was achieved in interrupting frequently with gradually increasing currents. The heat created by radiation and particularly by the positive ion bombardment of the cathode was sufficient to free the electrodes from adsorbed gases. A satisfactory conditioning of the electrodes required about 100 operations. All interruptions have to be started at a vacuum in the vessel of 10^{-4} millimeter of mercury or better. The use of vacuum-melted material, of course, would shorten considerably the time required for the conditioning.

Once the electrodes are conditioned properly, it was found to be of no advantage to operate the switch at pressures below 10^{-4} millimeter of mercury. Higher pressures result in a considerably longer time of interruption, as will be shown later.

An important property of the vacuum switch is the fact that the pressure in the vessel does not necessarily increase as a result of switching. With the vessel disconnected from the pumping system, a definite constant working pressure estab-

lishes itself in the vessel as a result of frequent switching. In the course of the experiments, the vacuum switches often were disconnected from the pump for hours, performing thousands of identical operations, without resulting in a change of the vessel pressure.

The working pressure was found to vary with the vessel diameter, the current, and the electrode material. The working pressure even can become appreciably lower than the pressure which is present in the vessel before the interruptions of currents. This behavior indicates that a strong pumping action is initiated by the interruption of currents. The observed constant working pressure thus represents an equilibrium between this pumping action and the gases and vapors which necessarily evolve from the electrodes. Real and virtual leaks, of course, also will affect this equilibrium. The pumping action is based on two distinct processes, both of which result from the sputtering of the cathode material. One process acts like a diffusion pump, whereas the other is based on the getter action which some materials like molybdenum display very strongly. The mechanism of the diffusion pump like process is as follows: The sputtered cathode material diffuses at high speed to the walls. Gas molecules present between the discharge region and the walls then are caught by the diffusing metal atoms and are plastered on the walls. These gas molecules are bound firmly to the walls and can be freed only when the walls are heated above 300 degrees centigrade, as is well known from the case of glow discharge tubes. Pumping in the manner described will occur when the distance from an active spot on the cathode to the nearest section of the wall is of the order of the mean free path of the gas in that region. This mean free path is a measure for the collision probability between the gas molecules and the sputtered particles. Under the conditions of the experiment, it always was found that the mean free path corresponding to the pressure in the vessel (measured with the ionization gauge) was several times larger than the average distance S of the active spots to the wall. This can be explained by the fact that as a rule the evaporating metal atoms greatly outnumber the gas molecules in the volume exposed to the blast of sputtered material. For example, during an interruption of 25 amperes with copper electrodes, the evaporated copper atoms outnumbered the gas molecules by a factor of fifty. The fact that the mean free path is larger than the distance S means that only a fraction of the metal atoms succeed in plastering gas molecules to the walls. The actually resulting reduction of gas molecules, partially balanced by the evolution of gases from the electrodes, thus will maintain a lower gauge pressure than that corresponding to a mean free path equal to the distance S.

It was found that the working pressure p, as measured by the gauge, varies inversely with the baffle or vessel diameter d, as $p_1/p_2 = d_2/d_1$.

This relation holds well for materials like copper and aluminum which do not display a strong getter action. Thus the judicious use of baffles may be of value in the switch design.

The current does not affect greatly the working pressure since it equally affects two opposing processes: the liberation of gas from the electrodes and the amount of sputtered material. The electrode material has a similar effect on the working pressure in affecting the evolution of gas as well as the sputtering. Materials which sputter very little (molybdenum, tungsten) require larger currents in order to display a strong pumping action.

The getter action also can contribute to an appreciable reduction in pressure. The fine film of sputtered material which collects on the walls is very efficient in absorbing gas molecules. Molybdenum displays a particularly strong getter action which was observed to last with diminishing intensity for 30 minutes or longer.

The reduction in pressure resulting from the two combined pumping actions can be considerable and is in part responsible for the fact that a current can be interrupted repeatedly in vacuum.

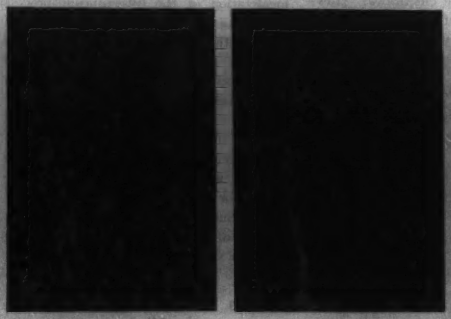
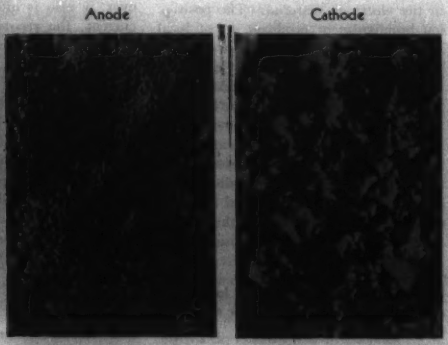


Figure 10 (above). Molybdenum electrodes (× 90)

Figure 11 (below). Carbon electrodes (× 70)



Factors Determining the Loss of Electrode Material

From the knowledge of the mechanism of interruption, it follows that the loss of electrode material caused by the interruption of currents will depend on the mass of material sputtered or evaporated at each striking of the arc and on the number of individual arcing episodes occurring during the time required for the interruption of the circuit. The mass of material sputtered at each striking of the arc is probably proportional to the energy dissipated in such an arc. The amount of mass sputtered per watt-second, however, will depend particularly on various physical constants of the electrode material and therefore will differ a great deal among various ma-

terials. For a given material the losses must thus depend on the over-all time to terminate the interruption and on the currents and potentials involved.

From the mechanism of interruption described earlier, it follows that the primary loss of material comes from the cathode. According to observations of the electrode surface, it is to be expected that the anode gains in mass by the sputtering of cathode material onto it.

Unfortunately, too little is known today about the mechanism of sputtering to enable one to make a thorough quantitative analysis of the various factors influencing the loss of electrode material. Two distinctly different types of sputtering have been observed in the course of the experiments. One is the atomic sputtering resulting from the evaporation of electrode material. The other type of sputtering is caused by occluded gases in the electrode material. The positive ion bombardment produces a fast local heating of the cathode surface which results in an explosive gas evolution and in the blasting out of chunks of material from the cathode. There has been visible evidence of such incandescent tiny chunks streaking from the arc region toward the walls and often rebounding from them. Carbon contains great amounts of absorbed gases and therefore displays with great intensity this second type of sputtering. The diffusion pump like action, described in an earlier part of this paper, is caused entirely by the atomic type of sputtering.

In what follows, the experimental results of the investigation on electrode material losses are given.

Distribution of Sputtered Material

All switching experiments resulted in a gain in mass of the anode and in a loss in mass of the cathode. The material sputtered from the cathode deposits on the anode, on the walls of the switch, and is reflected partially to the cathode. The loss of anode material which is known to occur from electron streams is overcompensated largely by the cathode material collecting on the anode surface.

The distribution of the sputtered material is determined chiefly by the design of the switch and particularly by the size and the shape of the electrodes. However, it also is affected slightly by the current, the recovery voltage, and the speed of separation of the electrodes.

Influence of the Gas Pressure

During this investigation, the pressure in the vessel was brought to a definite value before each interruption. Insignificant changes in losses were observed in interrupting at pressures ranging from 10^{-6} to 10^{-4} millimeter of mercury. At pressures above 10^{-4} millimeter of mercury, the losses increase rapidly because of a lengthening of the time of interruption.

If the pressure becomes too high, a permanent arc was able to maintain itself and switching action ceased. The lengthening of the time of interruption with increasing pressure obviously is caused by a corresponding decrease of the velocity of the radial gaseous diffusion.

Influence of the Shape of the Electrodes

The size of the anode was found to have no noticeable effect within the range investigated, that is, from 0.5 centimeter to 50 centimeters diameter. The curvature of the cathode has a pronounced effect, in increasing the loss and the time of interruption for a smaller radius of curvature. With a small radius of curvature, the radial travel of successive arcing episodes leading to extinction is no longer possible as it was in the case of a plate cathode. The restrikes, therefore, will be confined to a limited area around the former point of contact until the separation of the electrodes is too great to restrike the arc. This localization of the interruption process results in more continuous arcing episodes with a deeper localized heating of the area. This yields more gas evolution and evaporation and consequently heavier instantaneous arcing-currents result.

Influence of the Vessel Diameter

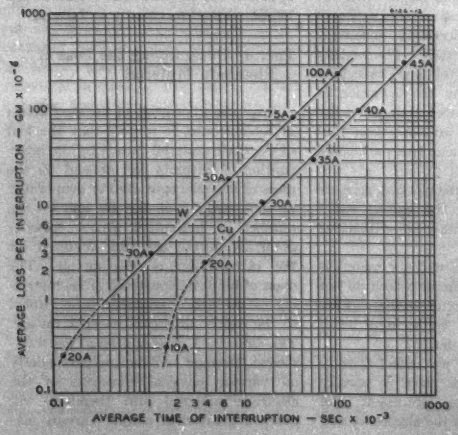
It was found that the loss of cathode material was slightly higher for smaller vessel- or baffle-diameters. The effect is very small and can be explained by the increase of the working pressure, resulting from the smaller diameter.

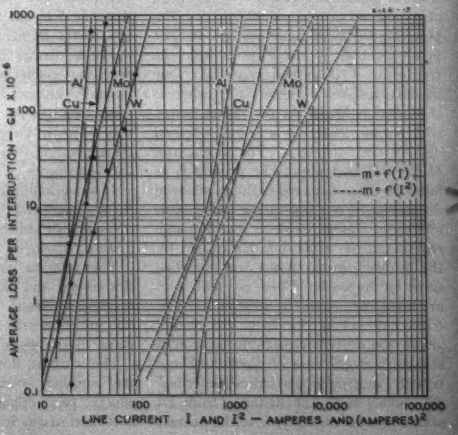
Figure 12. Average cathode loss versus average time of interruption of a d-c circuit

Cathode: 2-inch diameter plate
Anode: 1-inch diameter sphere
Opening speed 75 centimeters per second

Figure 13. Average cathode loss versus line current I and I^2 of a d-c circuit

Cathode: 2-inch diameter plate
Anode: 1-inch diameter sphere
Opening speed 75 centimeters per second





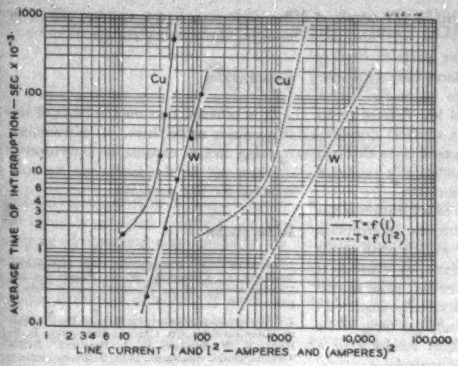


Figure 14. Average time of interruption versus line current I and I^2 of a d-c circuit

Cathode: 2-inch diameter plate
Anode: 1-inch diameter sphere
Opening speed 75 centimeters per second

Influence of the Line Voltage

The line voltage had no effect on the losses within the range investigated, that is, from 50 to 500 volts direct current. This is also in accordance with the findings of Sorensen and Jubitz. The line voltage is not of great significance in any such phenomena inasmuch as the recovery voltage is usually much higher. The recovery voltage is a much more significant variable and acts in two ways. One of these is to increase the chance of restriking and to increase the number of arcing episodes, thus lengthening the time of interruption. The other is directly to affect the sputtering. In the operation of glow discharge tubes, it is well known that sputtering increases materially once one enters the region of abnormal cathode fall, where the voltage increases with increasing current.

Influence of the Speed of Separation of the Electrodes

A few simplified considerations have to be introduced in order to understand the effect which the opening speed has on the loss of electrode material.

The energy equation[6] of a circuit having capacity C and inductance I is as follows:

$$1/2LI^2 = 1/2CE_r^2 + A$$

where I = line current, E_r = recovery voltage, and A = loss of energy in the circuit and in the switch because of heat and radiation. The term on the left side of the equation represents the magnetic energy stored in the system at the time of interruption. It is a constant for a given current. Referring to Figure 12, it is seen that except for small currents the loss of cathode material is directly proportional to the time of interruption T. Therefore the loss of energy A in the circuit is also closely proportional to T. For a given current and a given set of electrodes, a definite separation d of the electrodes is necessary for the interruption of the circuit. Hence $d = vT$, where v is the speed of separation of the electrodes.

If d would remain constant, then T would be inversely proportional to v. The experiments, however, have shown that the mass-losses of the cathode are always less than proportional to $1/v$. The reason for this is that an increase in the opening speed v tends to reduce A in making T shorter. Since the right hand side of the above equation is constant, it follows that the recovery voltage E_r has to increase. This actually has been observed. A greater separation d_1 of the electrodes therefore is required for the interruption of the circuit.

Since d is not a constant, it follows that an increase in velocity will always result in a decrease in mass loss which is less than proportional to $1/v$.

Influence of Line Current and Electrode Material

Figure 13 shows the average cathode material loss for various electrodes and different values of current flowing in the line prior to interruption.

In the same figure the broken-line curves show the relationship between cathode losses and I^2. This is a measure of the magnetic energy $1/2LI^2$ stored in the circuit before the time of interruption. Figure 14 shows the relation between the average time of interruption T and I as well as I^2.

The electrodes used for all the data given in Figures 12, 13, and 14 consisted of a 2-inch-diameter plate cathode and of a 1-inch-diameter spherical anode. The opening speed was in each case 75 centimeters per second. Referring to Figure 13, it is seen that the refractory metals give the smallest losses in the high current region. At lesser currents the different metals behave in a different fashion, the more refractory metals indicating a greater slope and the low melting point metals a smaller slope. It appears that two mechanisms may be at work in different current ranges. The difference in losses between the higher and lower melting point metals indicate why good conducting metals like silver and copper often are used in low current capacity vacuum switches.

The line current has a two-fold effect on the losses. Considering the energy equation of the circuit, it follows that the current determines essentially the sum of $1/2CE_r^2 + A$. It affects the recovery voltage E_r as well as the energy loss A. The latter term is particularly affected by the amount of evolved gases and vapors, which depend on the current magnitude and which greatly affect the time of interruption. It is obvious that well outgassed electrode materials, giving off only small amounts of gas, will result in small losses. It therefore is expected that vacuum-melted materials would give considerably smaller losses than can be expected from Figure 12 and Figure 13.

The surface conditioning as used throughout the present investigation is not sufficient for currents exceeding 150 to 200 amperes where craters are dug to a depth which is beyond the region outgassed by previous conditioning. This results in excessive gas formation, which would be dangerous, particularly for the case of sealed-off switches.

Essential Design Features

The mechanism of interruption, the behavior of the pressure, and the character of the losses of electrode material indicate that improvements can be made in the design of vacuum switches for moderate- and high-interruption duties.

The fact that a very high vacuum is not essential for the proper operation makes a practical design of a vacuum switch possible.

The vacuum vessel can be made of glass or metal, preferably stainless steel. The seals can be of the enamel type; welded, brazed, or soft soldered joints are also satisfactory. Glass-to-metal joints have to be ground and can be made vacuum-tight by means of a low-vapor-pressure wax, like picein. Greases should be avoided because they dissociate easily

under the intense radiation of the discharge.

The switch requires, for conditioning, a relatively low capacity diffusion pump backed by a medium-sized fore pump. The cooling of the traps can be achieved satisfactorily by means of a mixture of dry ice and alcohol.

It is expected that the judicious choice of seals and materials will make a permanently sealed-off vacuum switch possible. In this case it will be of even greater importance to use the correct vessel or baffle diameter by means of which full use of the pumping action can be made. Metal or glass baffles are also useful in shielding the insulating parts of the switch from sputtered material. A thorough outbaking will be required for a sealed-off switch.

The vacuum switch is ideally suited for the interruption of high voltage circuits. It is necessary, however, to reduce the evolution of gases and vapors as much as possible. Therefore, it is necessary to limit the current per contact and to choose electrode materials with small gas and vapor evolution. For larger currents, refractory metals are best suited.

The electrodes have to be conditioned in order to reduce the gas evolution. The conditioning by positive ion bombardment, as described earlier, limits the current to from 100 to 200 amperes per single contact. For larger currents, vacuum processed metals have to be used.

Exposure to air during the insertion (of new contacts, for instance) tends to contaminate the surface of such materials and therefore indicates the necessity of a short conditioning procedure preceding the operation of the switch after each shutdown period.

The interruption of higher currents and voltages also can be accomplished by multiple contacts. Such contacts will have to break with a fair degree of simultaneity.

All current carrying parts exposed to the vacuum should have large cross sections in order not to be heated appreciably by the normal line current or by short circuit currents of short duration. Too high a temperature of these elements would result in an undesirable evolution of gases from their surfaces.

The small distance of separation of the electrodes required for the interruption allows tripping the switch with great accuracy. With alternating current it is thus possible to interrupt close to current zero. In this way only small currents and recovery voltages have to be handled by the switch, resulting in a small loss of cathode material.

The loss of material and the time of interruption can be influenced further by the speed of separation of the electrodes. A speed of one meter per second or more should be used at the instant of separation.

The radius of curvature of the cathode should be large. The shape of the anode is not essential. For the interruption of alternating current the same contact arrangement as used for direct current is applicable provided the switch is always tripped at the same polarity. Both electrodes have to have a large radius of curvature and have to be symmetrical if the switch interrupts on either polarity.

By means of a magnetic field applied at right angles to the axis of the switch, the discharge can be confined to a small area. This considerably reduces the time required for the conditioning as well as reduces the necessary amount of vacuum melted material. A magnetic field of great intensity will disturb the focussing action and thus result in a faster deionization of the arc.

The use of parallel capacitors and resistors,[1,2] of course, also will improve the performance of a vacuum switch in reducing the recovery voltage.

Conclusion

It is believed that on the basis of the suggestions made here, a satisfactory working model capable of interrupting medium a-c or d-c loads can be constructed for test purposes.

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Semiconducting Shielding for A-C Power Cable

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ELECTRIC SHIELDING of a-c power cable is provided primarily for the purpose of directing and confining the electric field within the insulation so as to prevent the occurrence of unduly high electric stresses in dielectrically weak directions or regions of a cable. Martin Hochstadter laid down the principles governing such shielding in 1913, with particular application to impregnated paper insulated cables for high voltages.[1]

Such cable was not used widely during the following years, although the subject of shielding had been considered by many cable engineers in the United States. An excellent summary of shielding history and practice was presented in 1938 by L. F. Hickernell to the transmission and distribution committee of the Edison Electric Institute under the auspices of the Insulated Power Cable Engineers Association.[2]

During this time, various types of shielding, including the semiconducting type, were being considered. Semiconducting shielding may be defined as the practice of "partially" confining the electric field within the insulation by means of a semiconducting covering, its most important function being prevention of corona discharge. In 1928 cable with this form of shielding was described in an article by M. J. Lowenberg.[3] This article told of the failure of cotton-braided varnished-cambric cable, because of "arcs formed between the braid and the duct in which the cable was installed." Lowenberg then proceeded to tell how this trouble was eliminated by the substitution of a conducting cotton or asbestos braid for that of ordinary saturated cotton. The shielding effect of the braid, because of its partial- or semiconductivity, made possible the success of this venture.

Semiconducting shielding has been employed in a number of a-c cable installations in recent years, but an exact theory of its use has not been published. Consequently, most characteristics of this type of shielded cable have remained obscure, and the field to which semiconducting shielding may be applied safely has been limited unnecessarily.

It is hoped that the subject matter covered by this paper will assist in coordinating knowledge on the shielding of power cable, so that more effective use may be made of this electrical property.

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Theory of Semiconducting Shielding

While Lowenberg's paper dealt principally with the application of semiconducting shielding to varnished-cambric insulated station cables, probably its most important application is to rubber-insulated cables, as rubber is subjected to corona cutting from spark-generated ozone. The protective requirements of this type of installation may be met by semiconducting shielding.

Oscillographic observations of cable charging currents at ground points have verified the shielding effect of semiconducting cable coverings. Illustrative of this type of study are the oscillograms of Figure 1. They are typical of traces produced on the screen of a cathode-ray tube by the charging currents of three types of cable identical but for the electrical properties of their external coverings. Thus, the current traces of the cables having semiconducting and highly conducting shielding are smooth, and free of the high frequency components which are indicative of corona discharge. In contrast, unshielded cable under equal voltage conditions gives rise to a profusion of high frequency discharges. These oscillograms were obtained by carrying the 60-cycle charging current of the cable samples to ground through a 0.25 millihenry inductance, with the vertical plates of an oscillograph connected across the inductance.

To aid in interpreting the meaning of these observations, a theory of the electrical function performed by semiconducting cable coverings has been developed. This theory is based on an adaptation of the exact hyperbolic formulas for transmission lines to the circuit conditions present in a cable dielectric and semiconducting coverings. The simplified circuit of Figure 2 has been adopted as the electrical equivalent of cable insulation and outer coverings. The uniformly distributed capacity represents the dielectric, the conductance of which has been disregarded, its contribution to the admittance being negligible. The uniformly distributed resistance represents the semiconducting outer covering, the reactance of which also has been ignored, inasmuch as it has a comparatively minute effect on the impedance. The parallel capacity to ground likewise is neglected, as its operation reduces the current flow through the semiconducting covering by shunting a portion of the current, and, for practical purposes, this effect constitutes a factor of safety. Finally, the conductor is considered equivalent to the infinite ground in transmission calculations, inasmuch as for the cable lengths herein considered there is insignificant voltage drop along the conductor. The following formulas, expressed in co-ordinates adapted to measurement on the finished cable, were de-

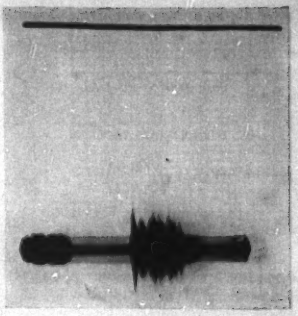

Figure 1. Charging current of shielded cable versus unshielded cable

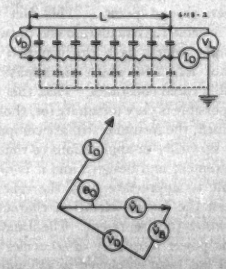

Figure 2. Equivalent circuit of cable insulation and outer semiconducting covering for single conductor cable

rived through these simplifying assumptions:[4]

$$V_B = V_L - \frac{V_L}{\cosh 0.001\sqrt{j(2\pi fcRL^2)}} \quad (1)$$

$$V_D = \frac{V_L}{\cosh 0.001\sqrt{j(2\pi fcRL^2)}} \quad (2)$$

$$I_b = (10^{-6})(V_L)(L)\sqrt{j\left(\frac{2\pi fc}{RL^2}\right)} \times \frac{\sinh 0.001\sqrt{j(2\pi fcRL^2)}}{\cosh 0.001\sqrt{j(2\pi fcRL^2)}} \quad (3)$$

$$\theta_b = \left[\tan^{-1}\frac{\sin 0.1146\sqrt{\pi fcRL^2}}{\sinh 0.002\sqrt{\pi fcRL^2}}\right] + 45° \quad (4)$$

where

V_L = vector line voltage to ground in volts

V_D = vector voltage drop across the insulation at a point midway between grounds

V_B = vector voltage drop lengthwise along the outer semiconducting covering, from the midpoint between two grounds to the ground points

I_b = vector current in amperes at the ground point from the half-length of cable on one side of ground

θ_b = power factor angle in degrees measured between the conductor and the ground point; this is the angle due to the power loss resulting from passing the charging current through the semiconducting shield to ground

f = frequency in cycles per second

c = capacity in micromicrofarads per inch length of cable

R = longitudinal resistance of the semiconducting covering in megohms per inch length of cable; this is the a-c resistance

L = one-half the distance between grounds in inches

Graphs for Use in Design of Semiconducting Shielded Cable

It will be noted that the foregoing formulas are functions of RL^2, RL^2 being a function of the a-c resistance of the semiconducting covering and the spacing between ground points. This fact has made feasible the calculation and drawing of graphs which have the common coordinate RL^2 and which encompass all probable cable constants. That this has been possible is very fortunate for, though simplified, the formulas still are comparatively unwieldy in applications to routine measurement and design; and it is quite difficult to appreciate fully the relation between the several electrical characteristics which they represent. The standard electric power frequency of 60 cycles per second has been employed in calculating the graphs, calculations being made for cables having capacities of 1, 5, 15, 30, and 50 micromicrofarads per inch length. Characteristics of cables possessing intermediate capacities may be obtained with sufficient accuracy for most practical applications by rough interpolation.

Figure 3 is a polar plot of the vector voltage relations at 60 cycles in a single conductor cable dielectric versus RL^2. Figure 4 is a semilogarithmic graph of the cable charging current versus the common abscissa, RL^2. Figure 5 likewise is a semilogarithmic graph with RL^2 as abscissa, and as ordinate the cotangent of the power factor angle, θ_b. Figure 6 is a similar graph of the maximum heat generation possible in watts in the inch of cable covering adjacent to the ground point, resulting from the passage of the charging current through the covering.

Figure 7 gives the thermal surface resistance in thermal ohms per inch length of cable for various cable diameters. These thermal resistance curves have been included because they are useful for determining the effect which semiconducting coverings may have on the thermal characteristics of a particular cable design, and because the data have been employed in checking the efficacy of the semiconducting shielding theory proposed. The curves have been derived from a paper published by S. J. Rosch.[5]

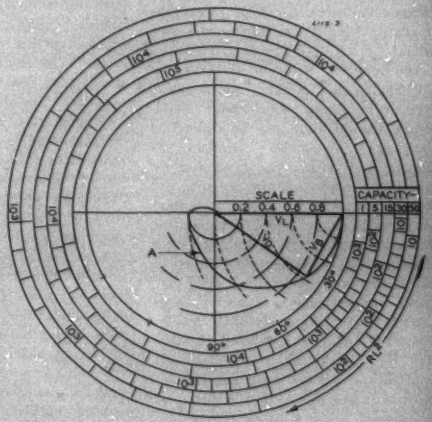

Figure 3. Dielectric vector voltages versus semiconducting shield resistance for single conductor cable

A—Locus of midpoint insulation and braid voltage vectors

Examples in Use of Graphs

To illustrate the use of these graphs in cable design, consider an aerial cable supported on metal rings 20 inches apart, rated at 10,000 volts to ground, and characterized by a capacity of 15 micromicrofarads per inch and a semiconducting shield resistance to alternating current of two megohms per inch. For this case L equals 10 and RL^2 equals 200.

According to Figure 3, V_B, the maximum voltage drop longitudinally along the braid, would be equivalent to 55 per cent of the line voltage, that is, 5,500 volts. Moreover, V_D, the voltage impressed upon the insulation at the midpoint between grounds, would be reduced to 86 per cent of the line voltage.

Figure 4 predicts a charging current of 0.5 milliampere for the half length of cable on one side of a ground ring. As the semiconducting covering has a lengthwise resistance of two megohms per inch, a maximum voltage drop of one volt per mil would be developed by the passage of this charging current, a stress much too low to cause corona discharge.

Figure 5 shows that this cable would not behave as a pure capacity; instead it would have a cotangent θ_b of approximately 0.37, which corresponds to an operating power factor of 35 per cent. Figure 6 indicates a loss of 0.5 watt in the inch of covering adjacent to the ground point. If this cable has an over-all diameter of two inches, and is installed so that there is a free movement of air about it, the cable will possess a thermal surface resistance of approximately 24 thermal ohms per inch of cable length, according to curve A' of Figure 7. Since the temperature difference required to liberate heat from a cable surface is equal to the product of the watts times the surface resistance in ohms, a temperature rise of 12 degrees centigrade will be produced in the semiconducting covering adjacent to the

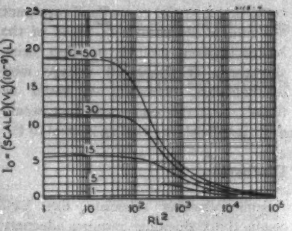

Figure 4. Charging current versus semiconducting shield resistance for single conductor cable

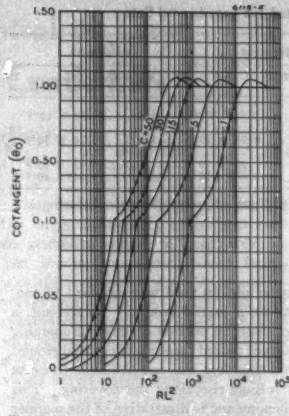

Figure 5. Power factor versus semiconducting shield resistance for single conductor cable

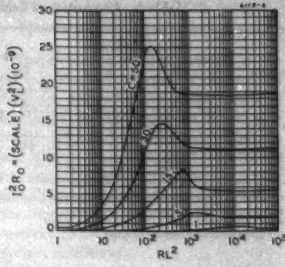

Figure 6. Watts loss versus semiconducting shield resistance for single conductor cable

ground point, because of the power loss resulting from passing the charging current through the semiconducting shield to ground.

Measuring Technique

In order to make available through the theory and graphs explained in the foregoing complete data relative to a particular sample of semiconducting shielded cable, seven constants must be measured. These are

1. The diameter over the outer coverings of the cable in inches, D.
2. The voltage applied for the measurements in volts, V_L.
3. The half-length in inches between ground loops, L.
4. The cotangent of the power factor angle of the combined semiconducting covering plus insulation, θ_2.
5. The ground point current corresponding to θ_2, I_0.
6. The cotangent of the insulation power factor angle, θ_1.
7. The capacity in micromicrofarads per inch length of cable, c.

In test procedure the first step is to measure the diameter, D, over the outer coverings. Next, the sample is prepared for the cotangent θ and ground point current measurements. The semiconducting covering is stripped from each end of the length, but is left intact on the center section. Wire loops are spaced on the active center section so as to form a number of π sections, similar to electrical models of long transmission lines or communication circuits. The number of sections and their length depend both upon the characteristics of the cable and the sensitivity of the bridge circuit employed for the measurements. Thus, in the analysis of a cable design having a low unit capacity and a high unit covering resistance, a larger number of sections of shorter length is necessary, than if the opposite be true. It is apparent that this aspect of the measurement requires an exercise of judgment and some experimenting before an efficient arrangement can be secured. In addition, the prepared sample must be placed on an insulated support, so that parallel capacity effects may be held to a minimum in accordance with the assumptions made in deriving the simplified formulas. With the sample so placed, all the wire loops except one are connected, through shielded leads, directly to the low tension side of a 60-cycle Schering bridge. The excepted loop is connected to the bridge through an a-c milliammeter or microammeter, so that the ground point current may be read. For the current measurement a ground loop adjacent to an end is preferable, because the current recorded at this point corresponds to the half-length current of the formulas and graphs. If the meter is connected to a loop in the center of the semiconducting section, twice this current is read, as it is collected from two half-lengths. The voltage now is applied and both the ground point current and cotangent of the power factor angle read. The half-length, L, corresponding to these measurements is recorded in inches, the voltage, V_L, in volts, the cotangent as that of θ_2, and the half-length current as I_0.

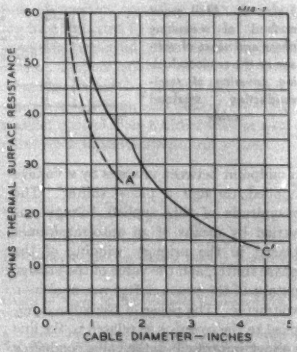

Figure 7. Surface resistance in thermal ohms per linear inch of cable for single conductor cable

A'—Braided cable in air
C'—National Electrical Manufacturers Association standard

Two measurements remain: the unit capacity, and the insulation power factor angle. To obtain these, the remaining semiconducting covering is stripped from the center section of the cable sample, and replaced with a highly conducting metal foil wrapping. Then the cotangent of the insulating power factor angle, θ_1, is measured, as is the capacity of the length in micromicrofarads. The capacity in micromicrofarads per inch, obtained from this measurement, is the unit capacity, c, employed in the formulas and graphs described in the foregoing.

The first step in employing these measured data to make an analysis of the characteristics of the semiconducting covering is to obtain the value of cotangent θ_0. This may be done by subtracting θ_1 from θ_2, the difference angle being θ_0, this procedure is in accordance with one of the original assumptions in deriving the theory, namely, that the insulation conductance was ignored so as to aid in simplifying the formulas and calculations. Having found the value of cotangent θ_0, and knowing the capacity of the cable in micromicrofarads per inch of length, the corresponding RL^2 may be obtained from Figure 5. In turn, the unit resistance of

Table I. Comparison of Calculated and Experimental Data

Sample	Cable Specification D	V_L[a]	L	R[a]	C[a]	Measured V_B	V_D	L_s[a]	T_s	Calculated V_B	V_D	L_s	T_s
A	1.62	5,000	39	0.01	8	120[b]		0.6×10^{-3}		125		0.63×10^{-3}	
		72,000	39						21				19
B		5,000	23	0.26	8.6	115[b]		0.24×10^{-3}		750		0.24×10^{-3}	
C		111	10	2.5	11.3	68[d]	100[d]			60	99		
		10,000	5	3.6	11.3			0.22×10^{-3}				0.21×10^{-3}	
D		2,500	5	4.4	10			0.048×10^{-3}				0.045×10^{-3}	

[a] = value of constants obtained from calculations based on 60-cycle Schering bridge measurements.
[b] = measured with vacuum tube voltmeter
[c] = measured with rectifier type milliammeter
[d] = null-type measurement, Figure 8

the semiconducting covering in megohms per inch of cable length may be obtained by dividing the value of RL^2 by the square of the half-length used in the cotangent θ_2 measurements. Having established the value of R, it becomes comparatively simple to predict the performance of the cable design for any ground point spacing by calculating the particular RL^2 and applying this to Figures 3 through 7.

Experimental Confirmation of Theory

Table I contains data obtained from cable designs which were selected to test the correctness of the theory. The choice of samples represents a range of 60-cycle semiconducting covering resistance from approximately 0.01 megohm to slightly over four megohms per inch of cable length. The agreement between values calculated from the cotangent measurements and those measured directly is very good for this type of measurement and thereby certify the practical worth of the theory.

Inasmuch as some interesting problems in measuring technique presented themselves in the course of this experimental work, it has been thought worthwhile to explain them in detail for their possible application to similar measurements in the field of dielectric research. Many measurements were made which did not fit in as well as was expected with the calculated theory. This was true particularly of the readings taken of the voltage built up lengthwise along the semiconducting covering by the flow of the cable charging current. For example, the measured V_B of sample *A* agreed very well with that calculated, but that of sample *B* did not. Both these voltages were read with a vacuum tube voltmeter, which was supposed to approximate a zero energy device. This it does for most measurements to which it is applied, but in the case of sample *B*, which possessed a covering of medium high resistance, the parallel capacity to ground of the voltmeter pickup prod was sufficient to constitute a partial ground. As a result, a considerable portion of the cable charging current passed through this partial ground and therefore was not available to cause a voltage rise along the covering. This phenomenon is illustrative of the manner in which parallel capacity to ducts and conduits affects the characteristics of semiconducting shielded cable.

The vacuum tube voltmeter was still more ineffective in attempts to measure the voltage characteristics of sample *C*, which was characterized by a high-resistance "semiconducting" covering. It was necessary to employ a true zero energy measuring technique for these readings. The circuit of Figure 8 shows the method by which this was accomplished. The voltage built up on the cable covering under test was balanced at a midpoint between grounds by a voltage applied through a phase shifter. The magnitude of this applied voltage was varied by means of an autotransformer placed in the primary winding of the phase shifter, and the value of the voltage output of the phase shifter was read by a voltmeter. The phase of the voltage applied to the covering as related to the line voltage impressed on the cable conductor was indicated by connecting a cathode-ray oscillograph as shown to form Lissajous figures.[6] A Schering bridge was used to indicate balance; thus, if the braid voltage were not balanced by the voltage from the second circuit, the latter would have to be superimposed upon that resulting from the load current.

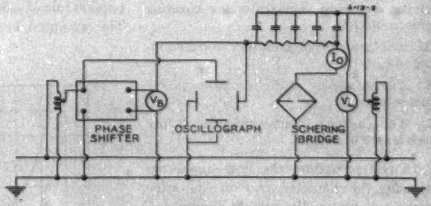

Figure 8. Null point method of measuring phase and value of voltage on the semiconducting covering of semiconducting shielded cable

constitute a partial ground and cotangent θ would be lowered as a result of the length between grounds in effect being shortened. If the braid voltage were overbalanced, cotangent θ would be raised; but the same cotangent would mean a null balance, that is, V equal to V.

Discussion

Semiconducting shielding, like high conductivity shielding, requires adequate grounding. If contact resistance or impedance is too high, arcing will occur at ground points with attendant destructive thermal and chemical effects.

Power loss in a semiconducting shield also may be, under certain conditions, sufficiently great to reduce the current carrying capacity of a cable markedly. Thus, consider a 2,000,000 circular mil cable, with a unit capacity of 15 micromicrofarads per inch, an over-all diameter of 2.7 inches, operated at 10,000 volts to ground. If RL^2 equaled 600, the power loss in the inch of semiconducting shield adjacent to the ground point would be 0.8 watt. Inasmuch as the thermal surface resistance of this cable is 23 thermal ohms per inch, a hot spot would result with a temperature rise equal to the product of watts and thermal ohms, or 18 degrees centigrade above normal. This temperature rise would result entirely from the passage of charging current, and would

Conclusions

A theory of semiconducting shielding has been presented which may be used as a guide in the application of this type of shield to electric power cable.

The electrical resistance required of a semiconducting shield for a particular cable installation is determined by several interrelated factors: the maximum spacing between ground points, the cable capacity per unit length, the line voltage, and the over-all diameter of the cable.

Automatic Control of Large Synchronous Condensers

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Synopsis: The considerations involved in the design of an automatic synchronous condenser control are discussed in this paper with an aim toward helping the designer and user of synchronous condenser equipment obtain modern and complete facilities in his design. A typical push-button-operated control for a large synchronous condenser is described and the diagrams involved are shown. The description includes a detailed résumé of starting sequence, protective device operation, and automatic control of voltage and load. Emphasis is put on the adaptability of push-button control to full automatic operation or remote operation by direct or supervisory control.

WHILE there is no clear line of demarcation between large and small synchronous condensers, it will best serve the purposes of this discussion to define large synchronous condensers as those having a rating of 5,000 kva or above. Numerically, there are about as many synchronous condensers below the 5 000-kva rating as above it, but the connected capacity of the large machines represents nine-tenths of the total capacity and the small machines only one-tenth. Hydrogen cooling appears on machines above 15,000-kva rating and at present will be found on about 12 per cent of these machines. There is reason to believe that hydrogen cooling will become more general in this class.

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Automatic control for condensers in the larger sizes offers advantages that are attractive to users of these machines. The starting procedure, which begins with the acceleration of the rotor and involves field application at the time that synchronous speed is reached and ends with applying full voltage to the machine stator, is a routine sequence that involves several operations that must be properly timed. The timing of these operations as well as the checking of various mechanical and electrical conditions during the starting sequence is a duty that can be more efficiently handled automatically than manually. Besides this very practical consideration of accurate procedure, there are other reasons for adapting automatic control. The time consumed in going through the starting procedure will be a minimum, and the operating personnel can be reduced in number or skill. These two features are of interest to operating supervisors who bear the responsibility for efficient and punctual operations in the system. Automatic operation, which is manually initiated and terminated, will have as its primary element a manually operated push-button or control switch. It is not difficult to extend this control to full automatic operation wherein the machine is started by undervoltage conditions and removed when machine load drops. Remote control of starting and stopping is another alternative. Such control simply is an extension of the local manual control over a direct wire or as a point on a supervisory control system.

Apparatus Associated With Large Synchronous Condensers

There are two general methods of obtaining starting torque. One method employs an induction motor directly connected to the condenser shaft as a source of accelerating torque. The second is a self-starting method wherein the reduced voltage is applied to the stator and the rotor accelerates on torque from the damping bars. Which of these two methods is to be used is determined by system conditions.

Should the system demand minimum disturbance, the induction motor should be used. If, however, it can tolerate the power swings involved in low voltage starting, this method will be found to be more economical in both equipment and space requirements.

Low voltage starting may be effected by using an autotransformer, tapped power transformer, series reactor, or a series-parallel stator connection scheme. The autotransformer scheme is the most generally used and is the basis of the control discussed in the following pages.

Two autotransformer connection schemes are in general use. Figure 1 shows the two schemes. They differ in the location of the starting breaker. The choice between the two is based upon breaker costs and economy of installation. Satisfactory performance is obtained with either connection, and neither has any operating advantage over the other.

Excitation for the field can be obtained from either a direct-connected exciter or a separately driven exciter. The latter is employed with hydrogen-cooled machines when it is desired to keep the d-c machine and its commutator out of the hydrogen chamber. The main exciter will be equipped with a main and differential field, the latter being used for overcoming the exciter residual so that the low voltages required for lagging capacity may be obtained. The main and differential field will be under the control of the voltage regulator system whose motor-driven rheostat and field forcing resistors will alter excitation to meet changing demands for reactive power output of the condenser. A pilot exciter on the same shaft as the main exciter will furnish excitation current for the main exciter fields. A field cubicle containing the field breaker and discharge resistor completes the excitation equipment.

The larger condensers will be equipped with bearing lift pumps that must be used as a means of floating the shaft on a film of oil prior to starting. There will

To be noted particularly is the fact that all pertinent electrical characteristics are functions of the product of the shield resistance and the square of half the ground point spacing.

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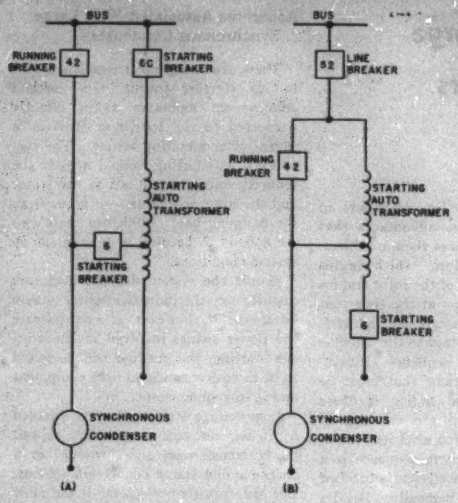


Figure 1. Synchronous condenser connections to autotransformer

be oil pumps employed in some cases for circulating lubricating oil in the bearings that must operate continuously as long as the motor is running. On other machines, oil rings provide lubricating oil circulation without the need for auxiliary oil pumps.

The instruments, relays, control switches, and associated devices will require switchboard mounting. Figures 2 and 3 show one section of a tunnel-type switchboard designed for the control of a 25,000-kva synchronous condenser. This type of construction has been adopted widely because the control switches and instruments are very accessible and constantly observable on the front panel of the switchboard, while the relays are easily attended on the back panel of the board. All wiring, terminal blocks, and fuses are concealed and protected within the tunnel housing. This area of the switchboard can be reached by entering a door at either end of the switchboard assembly. Drawout relays with built in test switches offer flexibility of handling when maintaining the relays.

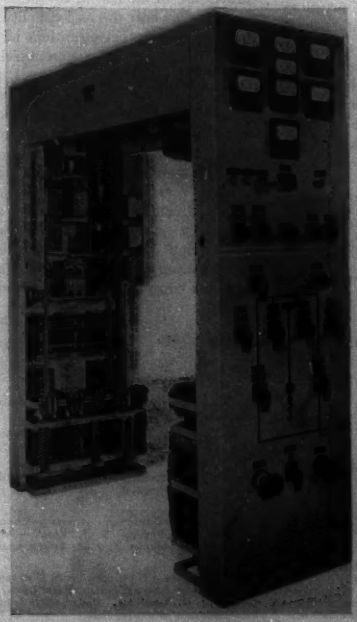
Starting Characteristics of Synchronous Condensers

When a condenser is brought up to speed with a direct-connected induction motor, the problems encountered in putting it on the line are exactly the same as those experienced when a generator is put on a line. The machine must be brought to synchronous speed, its voltage matched to the line voltage and synchronized with it. At the time when these conditions exist, the running breaker may be closed. The disturbance caused by closing the running breaker will be negligible if voltage and phase are matched closely.

When self-starting on reduced voltage is employed, the least disturbance is encountered if the field is applied before full voltage is put on the stator. Figure 5 shows the "V" curves for a typical condenser. The lower curve indicates the line current to be expected for various values of field excitation when operating the machine at 22.5 per cent rated voltage. The upper curve indicates line current variation with field excitation when the machine is operating at full line voltage. The intersection of these two curves gives a value of field current which may be used during starting if the leading reactive load during starting is to be the same before and after transfer from starting to running voltage.

The sequence of events in a typical start is shown by the graph in Figure 6. This shows the variation of reactive

Figure 3 (right). Rear panel relay arrangement of switchboard shown in Figure 2



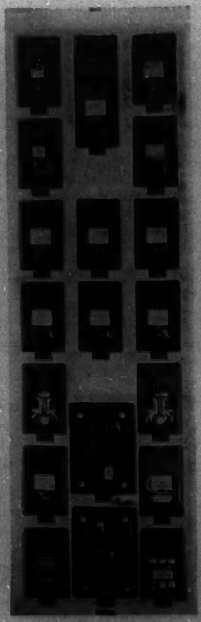


Figure 2. Tunnel-type switchboard section designed for synchronous condenser control

power, as seen by a graphic varmeter when the machine is accelerated and put on the line. The initial reactive inrush is lagging and diminishes in value as the machine accelerates. At half speed a slight drop is noted, but the decline continues smoothly until synchronous speed is approached. Hunting appears as a wavy trace in the graph and as synchronous speed is reached, the reactive power drops to a low steady value. When the field is applied, the reactive power becomes leading, building up in magnitude as the field builds up. The field eventually stabilizes and the machine is operated for a brief period under these conditions to assure that hunting has subsided. The transfer from starting to running voltage is made at this point. Although the actual transfer requires only a fraction of a second its effect is to reduce field flux to a low value. A subsequent delay is encountered in rebuilding the field. During the transfer, the field current will be dropped to nearly zero as the induced voltage in the field winding opposes the exciter voltage. The reactive power changes sharply during transfer from leading to lagging and returns slowly to leading again as field flux reappears.

The disturbance on a system caused by a synchronous condenser coming on the line is the net effect of the various reactive power swings encountered in the period extending from the time of initial inrush to final stabilized operation at full line voltage. The best operating point can be determined only by evaluating the effect of the individual disturbances during this period on the system to which the condenser is applied. The field excitation determined by the intersection of the "V" curves in Figure 5 will give satisfactory operation in many cases. A decrease in field current will increase the severity of the lagging reactive power peak encountered at the time of transfer. An increase in excitation will decrease this peak, but it also will bring the condenser on the line at a higher load, at both the starting and running voltage.

Table 1. Device Table for Schematic Diagrams

1 = start-stop push button
4 = master relay (multicontact type)
6 = starting breaker
14 = locked rotor protective relay (slow release telephone type type)
14X1 = pendulum relay (telephone type)
14Y1 = counting chain relay (telephone type)
14Y2 = counting chain relay (telephone type)
14Y3 = counting chain relay (telephone type)
14Z = pulsing relay (telephone type)
18 = acceleration relay (current operated induction disk type)
18X = auxiliary relay (solenoid contactor)
26 = thermal relay
26H = hydrogen temperature in machine
30 = annunciator relay
30-1, 30-2, and so forth = individual drops
30X = auxiliary relay (electrically operated, manually reset)
30Y = bell alarm cutoff relay (solenoid contactor type)
38 = bearing thermal relay
40 = field failure relay (solenoid contactor type)
41 = field breaker
43 = running breaker
46 = current balance relay (induction disk type)
47 = undervoltage, single and reversed phase relay (induction disk type)
48 = incomplete sequence relay (a-c timing relay)
49 = thermal overload relay (thermal lag—thermostatic relay)
51 = inverse time overcurrent relay (induction disk type)
52 = line breaker
53 = exciter voltage relay (instantaneous solenoid type)
56 = field application relay (a-c timing relay)
T_1 = short time contact
T_3 = long time contact
59 = a-c overvoltage relay (induction disk type)
63 = pressure relay
63H = hydrogen pressure in machine
63HB = hydrogen pressure in bottles
63OF = oil pressure in front bearing
63OR = oil pressure in rear bearing
63OX = auxiliary oil pressure relay (solenoid contactor type)
63W = cooling-water pressure
63WM = water detector relay
86 = lockout relay (electrically operated, manually reset)
87 = differential relay (induction disk type)
88 = auxiliary motor
88E = exciter motor
88EX = exciter motor breaker
88W = cooling-water valve motor
88WX = cooling-water valve motor relay
88O = oil lift pump motor
88OX = oil lift pump motor relay
90 = voltage regulator
90C = current regulator operating coil
90CX = a-c timing relay (induction disk type)
90CY = a-c fault detector relay (instantaneous solenoid type)
90CHR = antihunt coil—current element—raise
90CHL = antihunt coil—current element—lower
90CZ = auxiliary relay (multicontact type)
AR = quick-raise contact (voltage element)
AR' = quick-raise contact (current element)
AL = quick-lower contact (voltage element)
CR = raise contact (current element)
CL = lower contact (current element)
CSR = control switch raise
CSL = control switch lower
I = contact closed in indicating position of regulator transfer switch
LC = lowering contactor
LS = limit switch
M = contact closed in manual position of regulator transfer switch
NR = normal-raise contactor
NL = normal-lower contactor
NH = antihunt coil—normal raise and lower contacts
QR = quick-raise contactor
QL = quick-lower contactor
QH = antihunt coil—quick-raise and -lower contacts
R = contact closed in regulating position of regulator transfer switch
RL = red light indicating raise required
LL = green light indicating lower required
VR = raise contact (voltage element)
VL = lower contact (voltage element)

Figure 4. A 15,000-kva hydrogen-cooled outdoor synchronous condenser

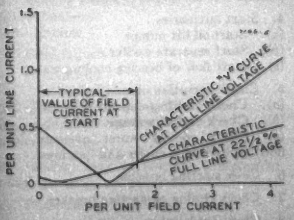


Figure 5. Characteristic curves for a typical synchronous condenser

An alternative method of starting suggests itself; that of accelerating the machine on low voltage, applying full voltage, and then applying field at the no-load value. The inrush of reactive power is far greater in this case when full voltage is applied than in the case where field is on before full voltage is applied. With this method, the phase and magnitude of the internal voltage of the condenser are less favorably matched to line voltage phase and magnitude when transfer is made than would be the case if the field were excited. Consequently, the inrush is greater with this method than with the method where field is applied before transfer is made.

Automatic Sequence for Controlling Synchronous Condenser

The following description applies to the control of a self-starting hydrogen-cooled machine operating from an auto-transformer. Figure 7 shows the single line diagram of this control and Figure 8, the control diagram. This is a typical scheme and would be altered in practice by changes in details to suit each particular application. The functional sequences are as follows:

PUSH-BUTTON STARTING

1. Operate push button.

2. Start incomplete sequence timing relay. Failure to complete the starting sequence in a definite length of time will cause lockout.

3. Check position of control elements.
(*a*). Check to assure that line breaker is open.
(*b*). Check to assure that starting breaker is open.
(*c*). Check to assure that running breaker is open.
(*d*). Check to assure that field breaker is open.
(*e*). Check to assure that motor-operated rheostat is in pre-set position.
(*f*). Check to assure that lockout relay has been reset.
(*g*). Check to assure that proper voltage and phase rotation exists on the a-c line.
(*h*). Check to assure that station battery voltage is at an operative value.

4. Start auxiliaries.
(*a*). Start oil lift pumps.
(*b*). Start separate exciter.
(*c*). Start flow of bearing cooling water.

5. Check operation of auxiliaries.
(*a*). Check oil lift pump pressure.
(*b*). Check exciter voltage.
(*c*). Check cooling water pressure (or flow) to hydrogen cooler and bearings.

6. Close starting breaker.

7. Check closing of starting breaker.

8. Close line breaker.

9. Check for machine rotation. Failure to rotate will cause lockout.

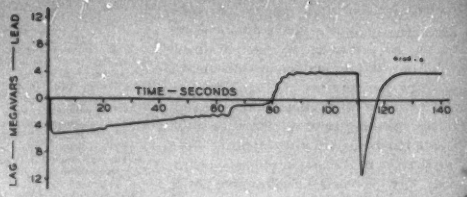


Figure 6. Graphic varmeter trace of reactive power drain by a 25,000-kva synchronous condenser during starting

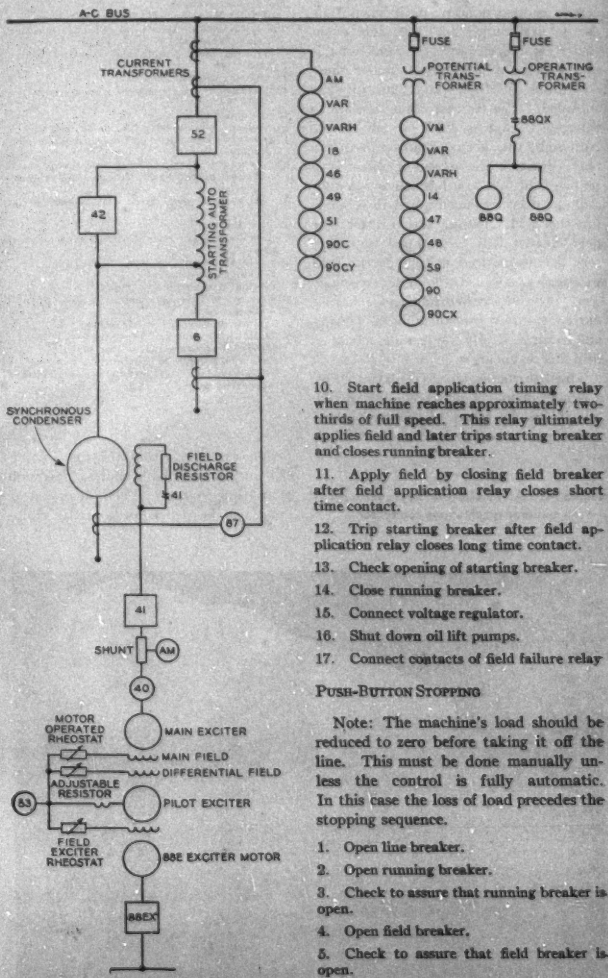


Figure 7. Single-line diagram of a typical synchronous condenser and associated equipment

10. Start field application timing relay when machine reaches approximately two-thirds of full speed. This relay ultimately applies field and later trips starting breaker and closes running breaker.

11. Apply field by closing field breaker after field application relay closes short time contact.

12. Trip starting breaker after field application relay closes long time contact.

13. Check opening of starting breaker.

14. Close running breaker.

15. Connect voltage regulator.

16. Shut down oil lift pumps.

17. Connect contacts of field failure relay

PUSH-BUTTON STOPPING

Note: The machine's load should be reduced to zero before taking it off the line. This must be done manually unless the control is fully automatic. In this case the loss of load precedes the stopping sequence.

1. Open line breaker.

2. Open running breaker.

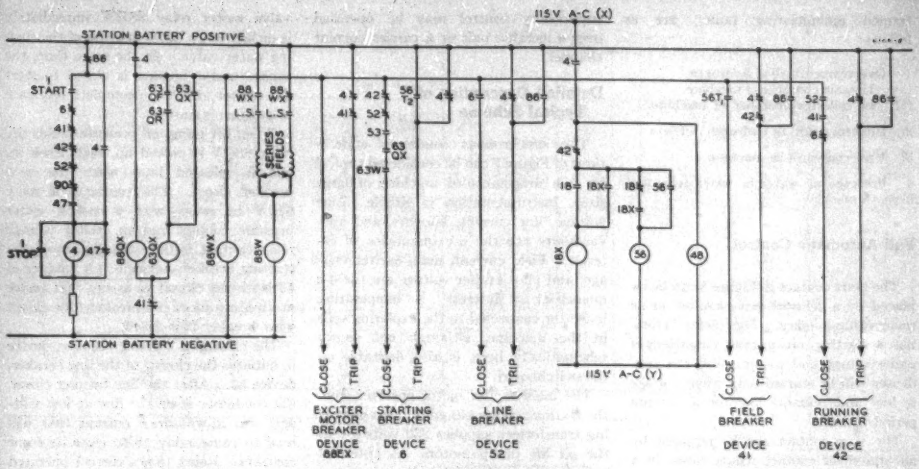
3. Check to assure that running breaker is open.

4. Open field breaker.

5. Check to assure that field breaker is open.

6. Open exciter motor breaker.

7. Drive motor-operated rheostat to starting position.



8. Shut down accessories: Hydrogen and bearing cooling water.

EMERGENCY STOPPING

1. Open line breaker.
2. Open running breaker.
3. Open field breaker.
4. Check to assure that field breaker is open.
5. Open exciter motor breaker.
6. Drive motor operated rheostat to starting position.
7. Shutdown accessories: hydrogen and bearing cooling water.

Voltage and Current Regulator

After the machine is on the line, voltage regulation of the bus to which it is connected can be delegated to a voltage regulator. This regulator increases or decreases field current as the bus voltage tends to decrease or increase. The machine, however, is limited by its capacity in the amount that it can correct line voltage. If it cannot raise the line voltage, it will overload itself in the attempt unless something is done to limit the reactive load that it takes. For this reason, a current regulator is added to the voltage regulator scheme on condensers. If the voltage regulator tends to raise excitation to a point where the line current would exceed the maximum permissible value, then the current regulator makes the voltage regulator ineffective. If the line current exceeds this value for any reason, then the current regulator lowers the excitation to a safe value.

Figure 8. Control-relay diagram for automatic control of a synchronous condenser

During fault conditions there would be a tendency for the current regulator to take immediate control and reduce excitation. Since this is a transient condition, a timing relay scheme is employed that holds the current regulator ineffective for a short time during the fault. If the fault persists, the current regulator begins to operate and reduces excitation.

The bus voltage value that the condenser maintains can be selected by adjustment of the voltage regulating rheostat in the voltage regulator circuit.

In some applications it is the purpose of the synchronous condenser to keep the power factor of a load constant even though this load may change rapidly and its power factor vary widely. Electric arc furnaces draw this type of load. In these cases it is necessary to employ a power factor regulator instead of a voltage regulator. The power factor regulator operates on load current and voltage and is sensitive to changes in the phase angle between the two. If the power factor drops below the desired value, a contact closes, causing increased condenser excitation. A raise in power factor above the regulating value decreases excitation. A current-limiting element must be used with the power factor regulator. However, quick raise and quick lower devices are not necessary, nor are the devices employed with the current regulator for rendering it ineffective during faults.

Protecting Synchronous Condenser

The abnormal conditions which may develop in the synchronous condenser, its control, and auxiliaries may be segregated into two classes. The first group embraces those troubles which are dangerous because of their damaging effect on the machine, auxiliaries, or connected lines. These demand immediate protective action and in general call for a complete shutdown and lockout. The second group includes the abnormal conditions that cannot be immediately responsible for damage or disturbance but demand attention before more serious consequential conditions arise. These faults demand immediate annunciation but do not require shutdown.

In the first group are the following conditions, conveniently termed lockout faults:

1. Locked rotor. Machine fails to rotate when starting voltage is applied.
2. Bearing overtemperature.
   (*a*). Condenser.
   (*b*). Exciter.
3. Field failure.
4. Overcurrent.
   (*a*). Instantaneous.
   (*b*). Inverse time delayed.
   (*c*). Long time overload.
5. Overvoltage.
6. Internal fault in machine (differential relay operation).
7. Phase current unbalance.
8. Failure to complete starting sequence.

The second group, which may be

termed annunciating faults, are as follows:

1. Overtemperature of hydrogen.
(*a*). In main chamber of machine.
(*b*). In collector chamber of machine.

2. Underpressure in hydrogen bottles.

3. Underpressure in machine.

4. Presence of water in water collectors beneath machine.

Full Automatic Control

The start contact in Figure 8 can be replaced by a delayed make-contact of an undervoltage relay. The delay eliminates starting on passing conditions of undervoltage and assures that the condenser will be started only when voltage is low and remains low for a definite period of time.

The stop contact can be replaced by an underload contact which closes in a definite period of time after the condenser load drops to a low value.

The voltage regulator in the full automatic station controls the load on the condenser. Since the voltage-adjusting rheostat will be pre-set, the regulator will alter excitation as required to maintain the bus voltage corresponding to this setting. The bus voltage which it will tend to maintain can be altered by changing the voltage-adjusting rheostat manually.

Supervisory Control

The control of starting and stopping is only one of the functions which must be considered when applying supervisory control to the condenser station. There also must be considered the supervision of protective devices, telemetering of the electrical quantities involved, and remote operation of the voltage adjusting rheostat.

A practical operating scheme would provide continuous telemetering of kilovars. The supervisory control would assign two points to the condenser control. One point would permit starting or stopping of the condenser. Following a start operation an indicating light would show when the master relay picked up and another light would show when the running breaker closed. A third light indication would follow the stop operation. The second supervisory point would operate the voltage-ajusting rheostat. Changes in kilovar load resulting from operation of the voltage-adjusting rheostat would be observed on the kilovar telemeter by the dispatcher. The supervisory control may be operated over a metallic pair or a carrier current channel.

Detailed Description of Typical Scheme

The synchronous condenser connections of Figure 7 can be considered typical for a hydrogen-cooled machine of large size. Instrumentation is simple. Line voltage, line current, kilovars, and kilovar-hours are the a-c quantities of interest. Field current, main exciter voltage, and pilot exciter voltage are the d-c quantities of interest. A temperature indicator connected to the exploring coils in the machine, although not shown schematically here, is also desirable on the switchboard.

The main exciter motor operates from the station service 440 volts. An operating transformer supplies 230 volts a-c to the oil lift pump motors. A potential transformer on the high voltage bus supplies the instruments and relays. A double secondary current transformer on the line side of the condenser breaker is connected so that one secondary operates instruments and relays and the other secondary operates the differential relay. During starting, the current in the condenser windings will be several times the line current, and a third set of current transformers may be employed in the autotransformer neutral to balance the currents on the two sides of the differential relay during a normal start. An alternative method is to use a differential relay that is spring-restrained from operation at the values of current involved during starting. This adjustment is normally within the range of conventional differential relays.

In Figure 8 the progression of the starting sequence can be followed by moving from left to right on the diagram. If, as will be seen from the circuit to coil 4, the lockout relay is reset, the starting push-button depressed, all breakers out, and the motor-operated exciter field rheostat in the proper position for starting, normal voltage conditions existing, relay 4 will pick up and seal in around all contacts except the lockout relay contacts. It will remain picked up unless short-circuited by the stop push-button contact or the reverse phase and undervoltage relay, or de-energized by the opening of the lockout relay.

Make contacts of relay 4 set up circuits to all the devices operated in the starting sequence. Linestarter 88*QX* is operated immediately after relay 4 picks up to start operation of the oil lift pumps. Likewise, the cooling water valve motor relay 88*WX* immediately is picked up to cause opening of the cooling water valve. At the same time, the exciter motor breaker is closed to start the exciter and the incomplete sequence relay timer is started.

When lift pump oil pressure builds up, relay 63*QX* is picked up, seals itself in, and is released later when the field breaker closes. The contacts of relay 63*QX* in series with a cooling water pressure contact and an exciter voltage relay contact initiate the closing of the starting breaker, device 6. A contact of 42 is in this circuit to assure that under no circumstances can breaker 6 be closed when breaker 42 is closed.

The closing of starting breaker, device 6, initiates the closing of the line breaker, device 52. After the line breaker closes, the condenser is on the line at low voltage, and it will draw current that will tend to cause relay 18 to close its front contacts. Relay 18 is a current-operated induction disk relay, and as the machine accelerates, it drops out on the reduced current, eventually closing its back contact. When 18 closes its front contact, it picks up relay 18*X*, which seals itself in. A contact of 18*X* in series with the back contact of 18 picks up and seals in timer 56.

At the end of a definite timing period, relay 56 closes the field breaker, device 41. Further operation of timer 56 causes starting breaker, device ß, to trip. The condition that the line and field breakers are closed and breaker 6 is open sets up a circuit to close breaker 42, thereby putting the machine on the line at full voltage.

The voltage regulator shown in Figure 9 is brought into service by the closing of breaker 42, provided the control switch whose contacts are shown as *RI* is in either the regulating or indicating position. This switch has "manual," "indicating," and "regulating" positions. In the "manual" or "indicating" position, the motor-operated rheostat may be raised or lowered by hand through the contacts *CSR* and *CSL* of a control switch. In the "indicating" position, the voltage regulator performs all of its functions except that it does not move the motor-operated rheostat. In the "regulating" position, the voltage regulator is in full operation.

The d-c motor which drives the motor-operated rheostat has a split series field. Energization of the armature in series with one field will raise excitation; the other will lower. Limit switches prevent excessive travel of the mechanism. Cam switches are connected in the rheostat motor circuit to drive the rheostat to the starting position after the running

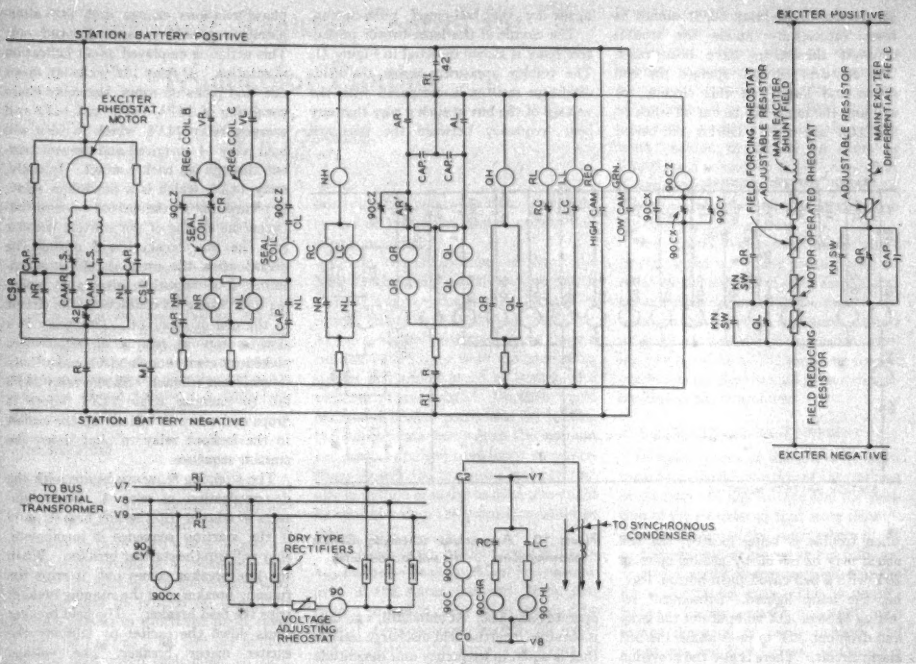


Figure 9. Voltage and current regulator connections used with synchronous condenser control

breaker closes on a shutdown. Contactors *NR* and *NL* control the rheostat under direction of the voltage regulator.

An indication comes from the voltage regulator element that a raise in excitation is necessary by the closing of contact *VR* in series with regulator coil *B*. Contactor *NR* is picked up by this action, and it not only operates the motor-operated rheostat, but picks up relay *RC* and antihunt coil *NH*. The latter functions mechanically to open contact *VR* even before any rise in voltage is felt on the bus. *VR* is permitted to close if, after a time delay, an adequate rise in bus voltage is not experienced. Relay *RC* provides back contacts to operate the indicating light *RL* and front contacts to operate the current element antihunt coil 90*CHR*. Similarly, a demand for reduction in voltage involves contact *VL*, regulator coil *C*, contactor *NL*, relay *LC*, and antihunt coil *NH*.

Sudden wide changes in voltage demand more rapid changes in excitation than normal operation through the motor-operated rheostat will provide. In this case, contacts *AR* and *AL* operate the quick-raise contactor *QR* or quick-lower contactor *QL*, as the case may be. These contactors energize the antihunt coil *QH* and also switch the field forcing or field reducing resistors into the circuit. In the event of a demand for quick raise, *QR* de-energizes the differential field also.

The current regulating coil is effective during moderate overcurrent conditions and also during fault conditions of extended duration. Normally the time delay relay 90*CX* is energized and holds the multicontact relay 90*CZ* up. This holds open the shunt around current element contact *CR* in the circuit to contactor *NR* and allows this current element contact to be effective. Likewise, a contact of 90*CZ* is held closed to make the current element lowering contact effective. The arrangement of the current element contacts is such that the demand for a raise in excitation is blocked if the current element finds that full load current is being exceeded. If current is high enough to demand reduction, the current element contact *CL* operates the motor-operated rheostat to lower the excitation.

During faults, the instantaneous overcurrent relay 90*CY* picks up, de-energizing relay 90*CX*, causing it to drop out. When 90*CX*, which is a magnetically damped induction-disk voltage relay, returns to its reset position, it closes its back contact and picks up relay 90*CZ* to put the current regulator in service again. Thus no attempt is made to regulate current or interfere with the operation of the voltage regulator during fault unless the fault remains on for an extended time.

The lockout and annunciator scheme is shown in Figure 10. The faults demanding lockout operate contacts that energize device 86. This is a manually reset relay which, when electrically tripped, closes its contacts and maintains them closed until it is reset. Its contacts drop out relay 4, energize the trip circuits of the various breakers, and set up the alarm circuit. Those conditions which require annunciation only, operate relay 30*X*, which is also a manually re-

set device. Like relay 86, it cannot be reset successfully unless the trouble contacts themselves have been reset. The contacts of 30*X* operate the bell alarm and lamp. In this circuit, the bell and the lamp will be cut off when 86 and 30*X* are reset. During the period

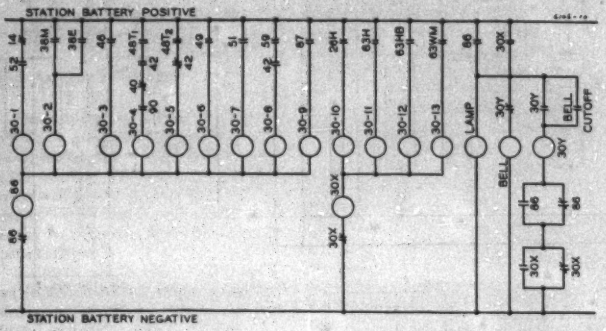


Figure 10. Annunciator schematic diagram showing alarm circuits and lockout relay

when trouble is being located, the bell alarm may be cut off by picking up relay 30*Y* with a bell cutoff push-button, leaving the lamp lighted. Subsequent resetting of 86 or 30*X* will put out the lamp and drop out 30*Y* to re-establish the bell alarm circuit. There is also the provision that the bell will ring if it has been cut off with the push-button following the operation of one relay, say 86, and the other operates, in this case 30*X*. A break-contact of 30*X* in the coil circuit of relay 30*Y* is adjusted to open just as it begins to pick up, and it drops out relay 30*Y*. After relay 30*X* closes its make-contact, relay 30*Y* may be picked up again by the bell-cutoff push-button.

The circuit of the locked-rotor protective relay is shown in detail in Figure 11. The voltage appearing across the field-discharge resistor is compared with the voltage of the bus in such a way that any beat frequency between the two will operate relay 14*Z*. At standstill, a voltage is obtained from the field-discharge resistor that is equal in frequency and magnitude to the voltage received from the bus potential transformer. It may have any phase relation with this potential, however, and may or may not pick up relay 14*Z*. As the rotor begins to turn, the phase relations change and 14*Z* alternately is picked up and dropped out. This action is employed as an indication of rotation. If relay 14*Z* picks up, drops out, and picks up again, the relay chain consisting of 14*Y*1, 14*Y*2, and 14*Y*3 will energize relay 14*X*1, which in turn will hold relay 14 energized and prevent trip-out through its back contact. Initially, relay 14*X*1, which is a pendulum relay, is picked up in the period of time between the closing of the starting breaker and the line breaker, and during the period when the rotor should start rotating, it is vibrating, alternately opening and closing its contacts in the circuit to the coil of relay 14. This relay is a slow-to-drop-out relay that will remain picked up even though 14*X*1 makes only intermittent contact. Should relay 14*Y*3 fail to energize relay 14*X*1 before it drops out, relay 14 will set up the circuit to the lockout relay to shut down the starting sequence.

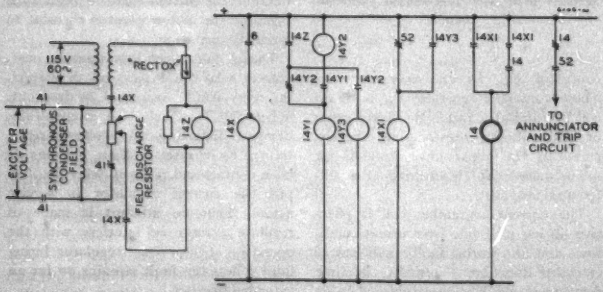


Figure 11. Locked rotor protective relay connection diagram

The stopping sequence begins with the de-energization of relay 4. Back contacts of relay 4 trip the line breaker, and if the starting sequence is incomplete, they will trip the starting breaker. When the line breaker comes out, it trips the running breaker, and the running breaker trips the field breaker. The field breaker shuts down the exciter by tripping the exciter motor breaker. The voltage regulator runs to the start position after the running breaker opens. The cooling-water valve motor runs to the close position when relay 4 drops out.

Emergency stopping does not respect sequential tripping. All breakers are tripped simultaneously by 86 and relay 4 is de-energized.

Conclusions

The operating complications involved in placing a synchronous condenser on a line demand that a certain portion of the control sequence be automatic. It is of practical advantage to design the sequence so that it is entirely automatic, allowing the user the choice of manual push-button control, remote supervisory control, or full automatic control.

Protective devices can be provided to protect against any contingency, and these devices either may sound an alarm to indicate an abnormal condition requiring attention or can lockout the machine in the presence of a dangerous condition.

Electronic Register Control for Multicolor Printing

W. D. COCKRELL
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Synopsis: The proper register for multicolor printing, that is, the printing of as many as five colors on top of one another to the required accuracy of a few thousandths of an inch, has been successfully solved by the use of phototubes and associated electronic equipment. In the system described, the electronic portion extends all the way from the phototubes to the thyratrons which supply the required current to energize the correcting motor armature in the proper direction and at the speed for correct register. A typical installation is shown in Figure 1.

The Problem

THE NUMBER of copies of each issue of present day popular magazines runs into the millions, and the only practical way to print such a large number of copies is by means of a continuous web press. This means that the colored illustrations must be printed on large rotogravure presses in which the paper speed may be as high as 1,000 feet per minute. At this high speed each color, in turn, must be printed, then dried while in motion so that it will not smudge as the next color is printed. This wetting and drying of the paper causes shrinkage and stretching which differs with each individual roll of paper, depending on its composition and the amount of latent moisture present. The paper often moves 30 to 40 feet through the drying section before it reaches the next impression cylinder. Also if a printing cylinder is even a few thousandths of an inch over- or under-size, the tension between stands will differ greatly. A typical press and control are shown schematically in Figure 2.

A particularly critical situation occurs when a "flying paste" is made from the end of one roll to the beginning of the next. As the splice passes through each succeeding section of the press, the tension drops to a low value, and the critical tension balance necessary for correct register is completely lost. If no correction is made, as many as 300 copies might be spoiled before the correct tension balance is regained.

Before the application of electronic control, the most usual way to check register was by means of a battery of control handwheels located at the folder. At intervals the pressman would draw a cut-and-folded copy from the outcoming stream and unfold it to be scanned for evidence of misregister. He then would make the proper corrections by turning the appropriate handwheel the amount necessary as judged from long experience. Even though the pressman was continually in motion as many as 50 copies might be spoiled before the correction could be made.

Needless to say, holding register manually has never been a pleasant job, particularly if the paper has not been permitted to season, that is, to remain in a special storeroom long enough for every roll to attain the same conditions of temperature and humidity. No attempt was made to hold register through a splice, and it was usually assumed that all copies printed during acceleration or deceleration of the press would be spoiled.

Fundamentals of the Electronic System

The first fundamental requirement of the electronic control is to check each printing cylinder after the first to find if it is in the correct position to lay its impression exactly upon the previously printed one. Next, when an error has been found, means must be set in motion to correct the error. Since the accuracy of register must be within 0.003 inch to be acceptable, it will be seen that the system must respond to signals as short as 0.00001 of a second, or ten microseconds, if satisfactory operation is to be obtained. A complete electronic system is the only practical solution.

The second requirement is to apply power to the correcting motor, as indicated by the amount of error found. Although other means could be used to accomplish this function, electronic circuits using thyratrons eliminated noisy moving parts which, at the large number of operations required, would present a serious maintenance problem.

The Error Detecting Equipment

In order to detect the error, we must have a standard indication of the position of the paper at any instant and the position of the cylinder at that same instant. Along a margin of the paper where it can be trimmed off, or placed in the fold, are printed a series of register marks in the first color to be used. This is usually yellow. Typical marks are 0.020 inch in the direction of paper motion, and about one half inch across. Although a mark only one fourth inch long is needed, the extra length permits greater latitude in lining of the paper and in correcting side lay or side register. These marks are equally spaced, as seen in Figure 3, usually 16 to the cylinder circumference. While fewer marks can be used, the larger number permits greater correction speed and thus higher accuracy and more nearly perfect copies.

As this thin yellow mark arrives near the succeeding cylinders for printing of

Figure 1. At each printing cylinder the web scanning head at right and the cylinder scanning head at lower left feed signals to the mixing panel at top. This determines proper operation of the correcting motor at lower right

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the other colors, its presence is detected by a phototube in the web head through an optical system which produces the effect of a very narrow slit, only a few thousandths of an inch wide. A dark blue glass filter provides a much better contrast between the yellow mark and the white paper.

The indication of the passage of the mark in front of the phototube leaves the web head in the form of a square wave of voltage of very short duration.

Detecting the Cylinder Position

Likewise, the position of the printing cylinder must be found so it can be checked against the relative position of the web. The basic indicating element is a disk or drum which contains the same number of axial slits as there are register marks on the first printing cylinder. A typical disk is ten inches in diameter, and the slits are one fourth inch wide. They are laid out so that the trailing edges of the slits are spaced very accurately around the circumference, as seen in Figure 4. The indicating point is not the whole slit but the trailing edge. An optical system directs light through this slit to a stationary slit before a phototube. The phototube and optical system can be moved around the drum to allow for setting up and for adjustment. The signal sent from this cylinder scanning head is a square voltage wave much broader than that from the web head, but which has a very accurate and abrupt trailing edge.

The Mixing Panel

The mixing panel, mounted on the press near each cylinder, may be considered the nerve center of the register equipment. Here the signals from the web mark and the cylinder disk slits are checked against each other and the proper correction action is initiated. For correct register, the cylinder disk phototube is moved until the trailing edge voltage change splits exactly the signal received from the 0.020 inch web mark. When this occurs, the correction circuit is balanced and no corrective action takes place. However, should the edge arrive even a few microseconds earlier or later than the midpoint of the mark, the difference is detected in the mixing panel, and the proper correction action is started. This comparison is made by charging one small capacitor as a result of the presence of the mark signal before the edge arrives, and charging a second capacitor after its arrival. These two charges then are compared and the difference is stretched out in time and amplified to apply the necessary correction. This correction signal, in the form of a small current of a few milliamperes, leaves the mixing panel in one of two leads, depending on which direction the correction is to be made. Perhaps the schematic drawing of Figure 5 will assist in clarifying the mixing panel action.

Since at this point the correcting motor control signal is at a low power level and in a low impedance circuit, it provides an ideal place to insert the push button stations desired for manual control of the correcting motor during setting up.

The mixing panel also contains an indicator "magic-eye" tube to assist the operator in setting up the panel and obtaining the original register adjustment.

The Motor Power Panel

Now that the correction signal has been obtained, it remains only to amplify the power for the correction, that is, the energy for the correcting motor. These correcting motors are usually d-c shunt gear-motors of about one half horsepower rating. They may operate differentials to change the relative position of the printing cylinders or may move the usual compensating rolls up and down.

The motors are run with full field strength to obtain maximum torque and fastest correction. The motor fields usually are fed from a common rectifier using phanotron tubes. The motor armatures are fed from 60-cycle alternating current through a pair of inverse-parallel thyratrons. Since the thyratrons are controlled rectifiers, if the first thyratron conducts a pulsating direct current, current flows through the motor armature in one direction. However, if the second thyratron conducts instead, the current flows through the armature in the opposite direction and opposite rotation is obtained. An iron core reactor in series with the motor armature smooths out the current and prevents excessive armature heating.

The only thing now required is a connecting link between the correcting signal from the mixing panel and the thyratron grid. This is supplied in the form of small saturable reactors in a bridge circuit which changes the phase of the grid. These reactors, of course, are saturated by the direct current from the mixing panel to regulate the grid phase as required. Figure 6 shows a complete motor control cabinet.

The Electric Circuit

Now that we have obtained a bird's-eye view of the operation of the equipment, let us retrace our steps and see the electric circuit used to obtain these results.

Figure 2. Schematic drawing of a multicolor gravure press with photoelectric register control

1. Cylinder register scanning disk
2. Cylinder scanning head
3. Web scanning head
4. Selector switch unit
5. Impulse comparison controller with "magic eye"
6. Main controller
7. Register adjusting pilot motor
8. Push button stations for manual adjustment

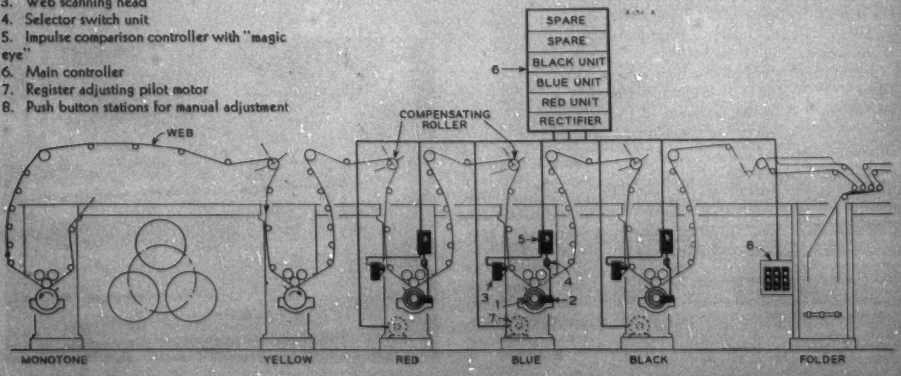

Figure 3. The register marks along the edge of the sheet usually are printed yellow and are almost invisible to the eye

Figure 4. Cylinder scanning head showing slits in disk, lamp in center and phototube at top

Vernier adjustment motor is at upper right. (View taken during test with covers removed)

The Web Scanning Head Circuit

The web head consists of an automobile headlamp-type bulb and an optical system to flood the path of the register mark with an intense spot of light at the point where the phototubes must scan it. An optical system picks up the light from the mark and conducts it to the slit in front of the phototube, and the blue glass filter, mentioned previously, provides a more positive light change.

Because the change in light on the phototube as the mark passes is so extremely small and so rapid, it is necessary to use an extremely sensitive amplifier to provide a signal sufficiently strong to be transmitted to the mixing panel. A two-stage amplifier is used, and if the signal is to be transmitted for a considerable distance, a third tube as a cathode-follower is included. The tube chassis must be shock mounted to prevent the vibration of the press from causing bad microphonic disturbances. Figure 7 shows the chassis removed from the web head.

Although there are no arcing parts in the head, it always is made dustproof and when conditions require, explosion-proof.

Cylinder Scanning Head

Since the slits in the cylinder reference disks or drums permit operation on direct light transmission rather than by reflected light, a single stage of amplification is sufficient to provide a satisfactory signal of the passage of the slit. Here again, however, if the signal must be transmitted a long distance, the cathode-follower tube should be added.

A special feature of the cylinder scanning head is the mounting of the optical system and amplifier chassis. These are mounted on a radial arm which is pivoted at the cylinder axis so that the complete system can be swung around the disk in a limited arc. This is provided to obtain proper register in setting up the equipment and for the vernier control of register during operation. The arm is moved by a small reversible adjusting motor which is controlled by push buttons at the folder.

Although only about one half inch of each drum slit is required for operation,

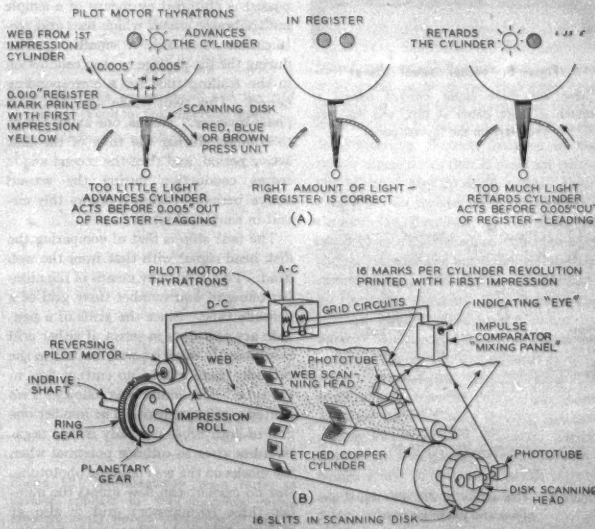

Figure 5. Schematic drawing to show the principle used to check register and to indicate the correction to be made

A. As impulse comparator evaluates the combined impulses from two phototubes
B. Photoelectric register control on four color press—one of four or more units shown

Figure 6. Motor control cabinet

There are three motor control panels at center, a spare panel at top, and the two rectifiers on the lowest panel

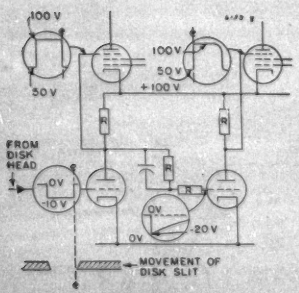

Figure 8. The action of the disk signal amplifier and phase-inverter

The wave shapes of the incoming and outgoing signals are shown also
e represents the instant that the trailing slit edge passes
Inserts are voltage wave forms

it is made much longer to permit the cylinder to be adjusted along its axis for best side-lay or register. This side register adjustment is usually a manual operation.

In some press installations a master cylinder scanning head is used rather than one at each printing cylinder. In this case the master unit is mounted on the main drive shaft, and optical systems for each color are located around it.

A single master cylinder scanning head permits a more compact installation than the separate heads, particularly when explosion-proof equipment must be furnished, but it can be used only with the compensating-roll type of correction.

Mixing Panel Circuits

The mixing panel must perform a number of functions. Let us take them up one at a time.

The incoming signal from the disk or cylinder scanning head is in the form of a square voltage wave which corresponds to the passage of the slit. In order to minimize the number of false operations due to random ink spots or paper blemishes, the region of active operation is limited to a fraction of an inch on each side of the correct register point. The signal from the slit provides a convenient live zone ahead of the correct point, while a similar active period after the slit has passed is obtained by means of a simple multivibrator circuit which uses grid rectification to charge a small capacitor during the slit passage to stop conduction in the trailing tube for a corresponding period. This twin triode also acts as a phase inverter. That is, one anode ceases to conduct during the time of the first active period, and then the second anode ceases conduction during the second active period. Figure 8 shows this circuit in simplified form.

The next step is that of comparing the disk head signal with that from the web head. This is done by means of the number one grid and number three grid of a pentode tube. Since the grids of a pentode act as valves in series, if either grid is sufficiently negative with respect to the cathode, there will be no current flow in the tube. The action is as follows: Two pentode tubes are used. The number one grid of both tubes normally is held negative, but rises to cathode potential when the marks on the web pass the phototube. But no current can flow unless the number three (suppressor) grid is also at cathode potential. These grids are controlled by the output of the two anodes from the twin-triode phase inverter, which cease conduction respectively before and after the register point. Thus,

Figure 7. The web scanning head chassis

The small change in phototube current due to the passing register mark is amplified by the two pentodes at the right. The tube panel is isolated from press vibration by the three rubber mountings seen behind the tubes

one pentode conducts when the mark is passing and the slit is passing at the same time. The second pentode conducts if the mark passes for a short time after the slit has passed, as determined by the timing circuit. If the mark passes exactly in register, the first pentode will conduct while the first half of the mark is passing, and the second half passing after the slit will permit the second pentode to conduct.

If the mark does not appear, there will be no conduction in either tube and no correction made. This is important, for it means that if the mark does not print, the correcting action ceases, but there will be no false correction as in some systems.

The mixing circuit and typical wave forms are shown in Figure 9. Both the twin-triode and the pentodes are operated from cutoff to saturation and thus act as limiters to produce uniform voltage

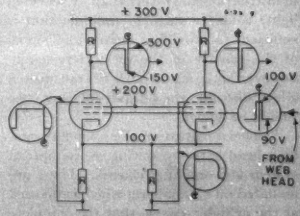

Figure 9. The circuit and wave forms of the pentode-tube mixing circuit

changes at the output. From the output of the pentode we now have signals which indicate the direction required for the correction, and by their relative duration, indicate the amount of correction needed.

The final function of the mixing panel is that of stretching out the fast microsecond pulses of the pentode output to a time sufficient for operation of the correcting motor. This is done by means of small capacitors which store the energy presented to them at each mark passage and permit it to leak off at a rate slow enough to permit motor operation to take place. This pulse-stretching circuit is shown in Figure 10.

Each time one of the two pentodes conducts, its corresponding capacitor begins to charge through the small rectifier tube. The capacitor charge next is amplified by a triode tube, and the output of this tube is passed on to the motor panel.

At this point, the action may be summarized thus. If the trailing edge of the disk slit passes at the same instant as the midpoint of the register mark, equal direct current will flow from the two triodes at the output of the mixing panel. If the register mark passes somewhat early so that there is an excess of mark before the slit edge passes, there will be a larger current in one triode, or if the register mark arrives late, there will be a larger current in the second triode output.

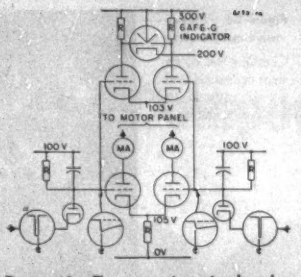

Figure 10. The correction signal pulse-stretching circuit, the output triode amplifiers, and the "magic-eye" indicator (6AF6-G) tube circuit

Assuming register mark center arrives before slit edge

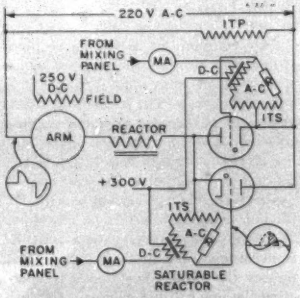

Figure 11. The power circuit and the grid control circuit for the correcting motor

The motor field is supplied from the common rectifier

The "Magic-Eye" Indicator

In addition to the control circuit, the mixing panel also has an auxiliary circuit, consisting of a twin triode and a double "magic-eye" tube which permits a visual indication of whether the register is balanced or is off in either direction. This circuit also is fed from the small pulse-stretching capacitors. If the mixing panel is mounted remote from the press, the indicator tubes may be mounted at the folder.

Manual Push Button Control of Correcting Motors

On its way to the motor control panel, the output of the mixing panel passes through the push button stations used for manual control of the correcting motor. These push buttons are used principally for setting up the work at the beginning of a run. When they are operated, the circuit from the mixing panel is broken, and direct current from a separate source is fed into the motor-panel circuit to operate the motor in the desired direction.

Motor Panels

For convenience, the motor panels usually are assembled together in a large floor-mounted cabinet. This cabinet also contains the common rectifier supply for the motor field and a rectifier to supply the mixing panels. A tap also is taken off this second rectifier supply for the push button operation. Each motor panel is complete in itself with jack and plug connections for all leads. In some installations, a spare motor panel is included in which the thyratrons are kept at operating temperature so that should a tube failure occur, the spare panel may be substituted for the inoperative circuit and a minimum of time lost.

The armature circuit consists of a reactor in series with the armature and the two inverse-parallel thyratrons which are used to produce the reversing action of the armature. Each thyratron has its own grid circuit which consists of a center-tapped transformer feeding a saturable reactor-resistor bridge, as shown in Figure 11. Since the a-c and d-c windings of the saturable reactors are electrically separate, the motor circuit is insulated from the control circuit coming from the mixing panel.

In operation, a larger current flowing in the d-c winding of the saturable reactor decreases its reactance, and the grid of the thyratron is phased forward. This permits the thyratron to conduct earlier in the cycle, and more current flows through the motor armature. The mixing panel circuit is so designed that, when register is correct, sufficient current will flow into the saturable reactors of each of the thyratron grid circuits to cause both thyratrons to conduct for approximately one-quarter cycle. The opposing currents balance in the motor armature so that it does not rotate but vibrates slightly at 60 cycles. However, when the register is out by even a few thousandths of an inch, the current to the reactors is unbalanced so that the thyratron currents are not balanced and the motor moves in the direction determined by the larger current. The shape of the voltage wave applied to the motor for various conditions is shown in Figure 12.

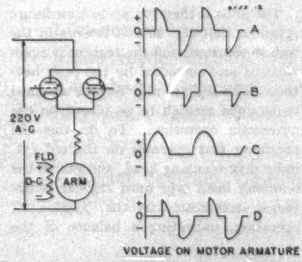

Figure 12. Representative wave forms of voltage applied to the correcting motor armature under various conditions of register error

A—Balanced, no motion
B—Forward slow
C—Forward fast
D—Reverse slow

When the controlling current is completely unbalanced, that is, when the register marks arrive completely before or after the disk edge arrives, full correcting motor speed is obtained. This is reduced to zero as the slit edge intercept comes nearer to the center of the register mark. Antihunt circuits in the mixing panel prevent overshooting.

Aids for Maintenance and Repair

In the printing business it especially is important that production schedules be

Figure 13. Mixing panel with cover removed

This shows "magic-eye" indicator tube at top, milliammeter jacks at left-center, test terminals at center, and connecting leads plugged in at bottom

Figure 14. Preventative maintenance

Checking the equipment operation with a small cathode ray oscillograph

met. Therefore, even short delays in press operation are serious. It has already been mentioned that the motor panels are provided with plug and jack connections and that sometimes a spare motor panel is added and kept warmed up for instant substitution without the delay of even the five minutes needed to preheat the thyratron cathodes. Although there are no moving or wearing parts on the web and disk scanning heads, or on the mixing panel, all of these are also provided with plug and jack connections, and a spare of each is often kept on hand for substitution whenever needed.

To assist in preventative maintenance and trouble shooting, milliammeter jacks and test terminals are located on the mixing panel, as seen in Figure 13. The milliampere readings of the output to the motor panel permit a quick checkup of the over-all mixing panel operation, while the test terminals permit key potentials to be seen on a cathode-ray oscilloscope to check the operation of the two scanning heads and the internal circuits of the mixing panel. To the experienced operator the characteristic flicker of the "magic-eye" indicator tube can convey much information about the over-all operation of the equipment.

Putting the Equipment Into Operation

In conclusion, let us follow the press operator as he puts the register equipment into operation when starting a new run on the press. The inkwells are filled, the paper is threaded, and the backing rolls are let down. The first copies coming off the folder look very little like the finished product, but if the press crew is experienced, the register will be within a fraction of an inch correct on all colors. Standing at the folder with a copy in front of him, the head pressman then presses the proper push buttons operating the one half-horsepower correcting motors to bring the cylinders into approximate register with the first color, usually yellow. First the red impression from the second cylinder comes into line, next the blue, and finally the black from the last cylinder.

The press is then run up to a moderate speed so that the normal tension in the web is obtained, and the register is again checked and corrected by the push buttons. The register may now be assumed to be good enough to be placed on the automatic operation. To do this the pressman first operates on the red cylinder disk scanning head, and moves the scanning head arm until register is obtained as indicated by the "magic-eye" operation, indicating a balance of the mixing panel output. He then throws the switch to automatic, and the red is locked in step with the yellow. He then repeats this process on the blue and on the black cylinder. Finally he returns to his normal station near the folder and checks the outcoming copies. Probably during the time he has been away the register has crept off a few thousandths. He now brings this back into accurate register by again operating the small reversible adjustment motor on the disk head optical system. Operation of the push button controlling the correcting motor at this time will have no effect because the automatic operation immediately would bring the register back to the previous setting.

After these refinements have been made, the register is locked in step in the correct position and will hold this through wide changes in press speed, through splices, and through the many differences in paper which may be found, such as tension, humidity, surface conditions, and others.

Conclusion

It was said in years gone by that only one copy in 25 was perfectly registered. With electronic register control, fewer than one in 25 will be found which are not perfectly registered. Electronics has provided a quiet, precise method for holding register. Since there is no wear of critical parts the high accuracy which can be obtained will continue throughout years of untiring service.

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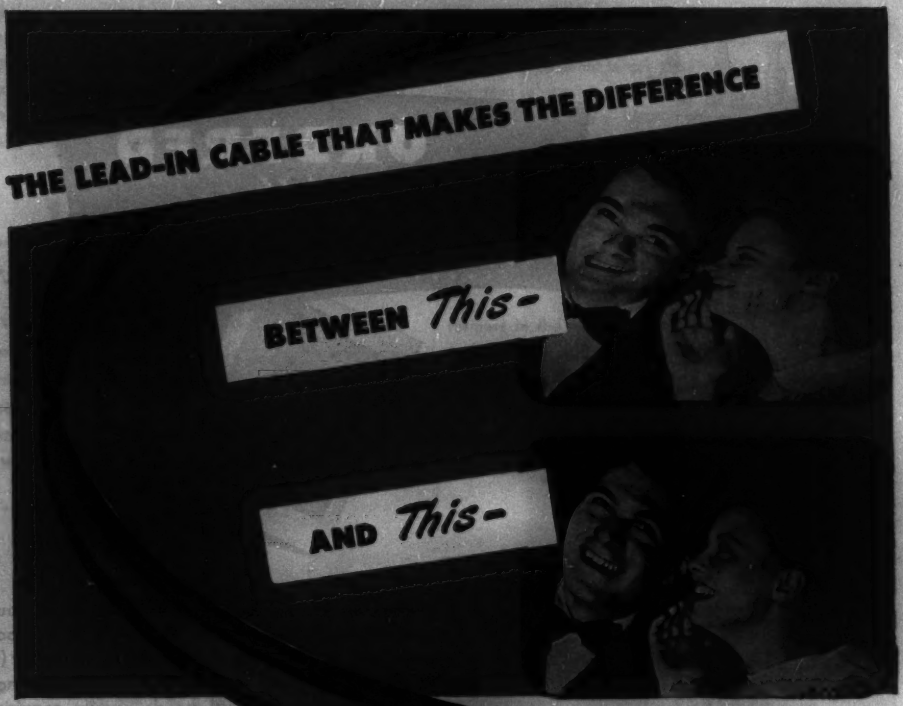


INSULATED WITH Du Pont POLYTHENE

With the home television set, much of the attenuation and distortion of images that sometimes occurs on the screen may arise in the lead-in cable from the antenna to the instrument. But not with the new Type ATV cable shown here. With this cable, attenuation is minimized . . . images are strong and clear.

The unusual design of this new lead-in line deserves much credit for its high effectiveness. But note—what makes this design possible is the excellent electrical properties of the insulation, of Du Pont polythene.

Because of polythene's remarkable dielectric strength, a thin coating of it is all that is needed. Polythene's low power factor makes it unusually effective in every type of high-frequency circuit. Credit also polythene's light weight (specific gravity 0.92) and its ability to retain its toughness and flexibility over a wide range of temperatures.

For complete data sheet on polythene, write to E. I. du Pont de Nemours & Co. (Inc.), Plastics Dept., Room 168, Arlington, N. J.

Du Pont manufactures polythene molding powder.

Commercial extruders convert polythene into the form of

Type ATV two-wire polythene-insulated cable, for use as television lead-in line between antenna and receiver, made by Anaconda Wire & Cable Co. (Photo 2.5 times actual size.) This rugged, flexible cable, one of the lightest of its type, has an attenuation of 0.75 db/100 feet, and an impedance of 300 ohms at 50 megacycles.

DU PONT
REG. U.S. PAT. OFF.
Plastics
BETTER THINGS FOR BETTER LIVING THROUGH CHEMISTRY

All cover bushings

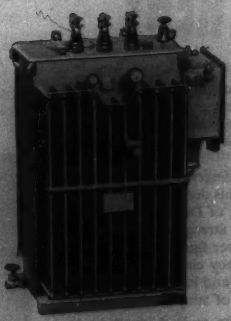
ORDERED

Right out of the catalog

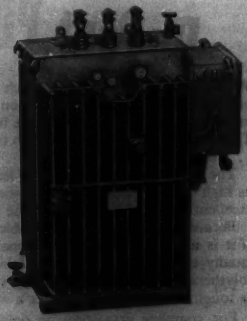
H-V cover bushings
L-V cable entrance without switch

Because G-E "RM-listed" power transformers are built by repetitive manufacture, they open the way to important savings. The wide range of selection they offer (as to auxiliary mechanical features and electrical ratings) meets many of the special needs usually requiring custom-built equipment.

H-V cover bushings
L-V cable entrance with disconnect switch



L-V cover bushings
H-V cable entrance without switch



L-V cover bushings
H-V cable entrance with switch

RM-listings cover step-down transformers in the range of 2400 to 66,000 volts. That your specifications can be met with "tailor made" exactness is demonstrated by the fact that the mechanical combinations shown here, applied over the full range of standard electrical ratings, furnish some 21,000 possibilities from which to make your selection.

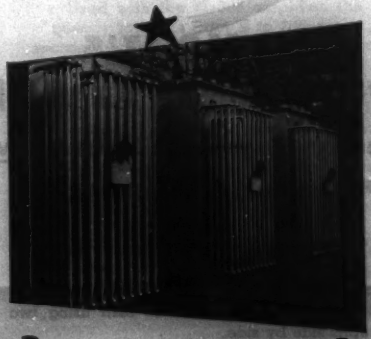
Savings are also made possible in providing additional margin for load growth and heavy short-time overloads, by using a somewhat larger RM-listed unit, which will cost less than a special "in-between" rating. (A 2500-kva, 22,000-volt RM-listed transformer will cost less than a special 2400-kva, 22,000-volt transformer.)

—YET DELIVERED "*Tailor made*" FOR YOUR JOB

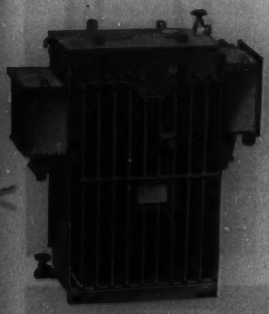
You have merely to study the factory-assembled transformer arrangements shown here in order to realize the extent of the logical and practical simplifications which have been made possible by RM design. Installation economies are apparent at first glance.

If you are considering the purchase of power transformers in the near future, it will pay you to ask for Bulletins GEA-4283 and GEA-4338A, which will give you complete data on RM design. Call your local G-E representative or write to *Apparatus Dept., General Electric Company, Schenectady 5, N. Y.*

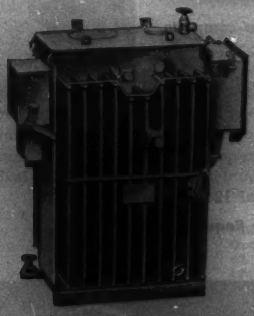
RM-LISTED POWER TRANSFORMERS



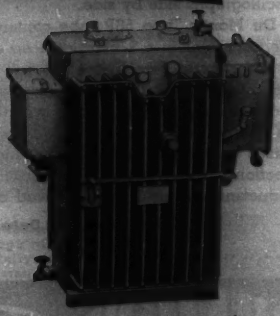
Installation of 3 G-E repetitive-manufacture power transformers with cover bushings.



H-V and L-V cable entrances without switches



L-V cable entrance with switch
H-V cable entrance without switch



L-V cable entrance without switch
H-V cable entrance with switch

GENERAL ELECTRIC

A typical application showing how the type 5SP may be used to examine both the input signal to a circuit and the resultant output signal. Here, a square wave has been applied to an L-C network. Both input and output signals appear simultaneously on the face of the Type 5SP. Either signal may be expanded for detailed study.

DU MONT'S
TWO-GUN TYPE 5SP
Cathode-Ray Tube Shows Two Patterns Simultaneously

NOW—a superior method for viewing *two* independent signals *simultaneously*. Not subject to the frequency limitations encountered when using the electronic switch. More convenient than using two oscillographs side by side.

Du Mont's Type 5SP tube contains *two complete* electron guns in a 5-inch flat-faced envelope. The X, Y and Z axes of each electron gun can be independently controlled, thus permitting two traces to be spaced from zero to any value desired within limitations of the tube diameter, and also modulated as desired. Adequate shielding betweens guns and deflection plates minimizes "cross-talk" particularly at higher frequencies. Short side-wall connections to deflection plates minimize shunt-input capacitance and lead inductance. Army-Navy approved diheptal 12-inch base.

Further Details on Request

© ALLEN B. DU MONT LABORATORIES, INC.

DUMONT *Precision Electronics & Television*

ALLEN B. DUMONT LABORATORIES, INC. PASSAIC, NEW JERSEY · CABLE ADDRESS: ALBEEDU, PASSAIC, N. J., U. S. A.

Now you can make Direct-Inking Recordings from D. C. to 100 cycles per second!

Brush Magnetic Oscillographs Revolutionize Measurement-Recording

Brush Magnetic Oscillographs may be used for detailed recording of virtually every conceivable type of measurement that can be made in the form of electrical impulses. The Magnetic Pen Motor is capable of recording a D. C. signal. Used with the BL-905 amplifier, the frequency range is *from .2 to 100 cycles per second.* Recordings are *direct, instantaneous, ink-on-paper* graphs.

Usefulness of Brush Magnetic Oscillographs is almost unlimited. Can be used for recording strains, pressures, vibrations, temperatures, light intensity, displacement counting, phase relationships, currents and voltages acceleration and deceleration, inertia and countless other phenomena.

Brush engineers will be glad to work with you in determining the equipment needed to meet your particular problems. Write today for detailed bulletin.

The Brush Single-Channel Oscillograph—ideal for counting, temperature recording, etc. One recording penmotor and pen. Three-speed paper drive, 5, 25, 125 mm per sec. Chart paper 2¾" wide.

The Brush Double-Channel Oscillograph with cover off. Especially suited for synchronizing problems where two simultaneous recordings are required. Two recording penmotors and pens. Three-speed paper drive, 5, 25, 125 mm per sec. Chart paper 3⅛" wide.

The BRUSH DEVELOPMENT Company

3405 Perkins Ave., Cleveland 14, Ohio

Canadian Representative:
A. C. Wickman (Canada) Ltd., P. O. Box 6, Station 'N', Toronto 14

3 NEW TOOLS FOR PRODUCTION LINE OR LABORATORY

• SAVE TIME

• SAVE MONEY

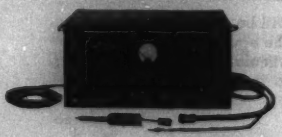
The newly-developed instruments shown on this page are already proving their value in scientific and industrial processing fields. Expert design assures simple installation, easy operation, and a minimum of maintenance. Fast and accurate performances result in time and cost savings. These tools solve newly-encountered problems and replace old tedious methods. Recently-found applications of these instruments are constantly simplifying testing procedures and improving production rates.

●Newly-discovered application—new G-E leak detector is being used in a test for leaks on a large transformer cover. This method is quicker and does not contaminate the oil as the old method using soap solution and air pressure did.

1. NEW LEAK DETECTOR DOES FASTER, BETTER JOB . . .

In the application shown, the G-E leak detector is being used to test studs on transformer plates for oil tightness. Contamination of material, which results from the method using air pressure and a soap solution, is avoided since helium, which is inert, is used as the tracer gas. The leak detector is a special mass spectrometer which locates leaks in closed systems—even small leaks in the presence of large ones. It is used to test leakage in radio tubes, refrigerator parts, boiler tanks, piping systems, and other closed systems which can be evacuated. For further information, write us.

2. ION GAGE MEASURES HIGH VACUUMS



With the G-E ion gage, the highest vacuums ordinarily encountered in factory or laboratory processes can be measured or monitored continuously. This instrument is used to measure high vacuum in process-control spectrometers, electronic-tube manufacture, vacuum-pump testing, and as a vacuum-failure relay. It measures pressures of 10^{-4} mm (0.1 micron) to 10^{-9} (0.0001 micron) of mercury. The ion gage circuits permit the indication of small pressure changes and the measurement of slow pressure drifts—without the inconvenience of continual adjustment. The gage tube filament is protected by automatic disconnection of the current at pressures above 10^{-4} mm. Write for Bulletin GEA-4529.

3. X-RAY PHOTOMETER FOR CHEMICAL ANALYSIS

Independent of the physical or chemical state of the material, the X-ray photometer indicates the concentration of one chemical element in the presence of others. Typical applications include the determination of the sulphur content of oil, the ash content of coal, and the halogenated hydrocarbon content of plastics. Built for continuous use, the X-ray photometer operates on the principle of X-ray absorption between sample and reference. Write for further information.

IN ADDITION, G-E BUILDS:

- Coil testers
- Coil-turn counter
- Core-loss test equipment
- Dew-point indicator
- Dew-point recorder
- Differential analyzers
- Pressure gages
- Thickness gages
- Thermal gas analyzer
- Insulation-resistance meter
- Luximeter
- Mass spectrometer
- Mercury-vapor detector
- Metal detectors
- Magnetic comparator
- Reflection meter
- Repeated-scrape abrasion tester
- Resistance comparator
- Schlieren equipment
- Sound-level meter
- Spectrophotometer
- Standard roughness specimens
- Tachometers
- Time-interval meter
- Vacuum gages
- Vibration-fatigue equipment
- Viscosimeter
- Winding-insulation tester
- Nuclear research equipment

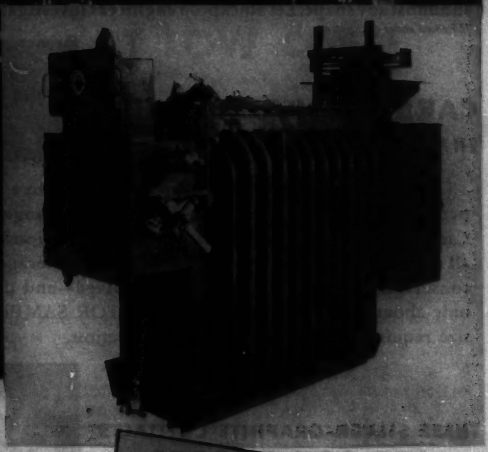
The products listed are only a part of the complete line of measuring and testing tools offered by the General Electric Company. Our engineers are specialists in adapting these devices to your individual needs. For help and advice, call or write the G-E office nearest you. SPECIAL PRODUCTS DIVISION, APPARATUS DEPT., GENERAL ELECTRIC, SCHENECTADY 5, N.Y.

GENERAL ELECTRIC

AMERTRAN

Abestol-Immersed

TRANSFORMERS



have a fine safety record in congested network service

AMERTRAN Abestol, the insulating coolant in these transformers, cannot burn nor liberate inflammable gases. For this reason, Abestol-immersed units are permitted by the National Electrical Code to be installed *without* vaults, either indoors or outside. In congested business and industrial areas, including some of the most intricate network layouts in the country, AmerTran Abestol Transformers have established a perfect record of safety. In most cases, also, their installation has been effected at substantial savings in cost. Since no vault construction is required, and since there are no installation restrictions, they are installed to take full advantage of shortened secondary lines and better voltage regulation —at load centers.

Install them anywhere—on platforms, on the floor with the load, in basement or on the roof. They are safe, efficient and economical, for every distribution use.

★ Non-inflammable
★ Require no vaults
★ Meet full requirements of National Electrical Code
★ Mounted anywhere—save valuable space
★ Eliminate necessity for long secondary lines
★ High electrical efficiency

AMERTRAN

AMERICAN TRANSFORMER CO., 178 Emmet St., Newark 5, N. J.

Pioneer Manufacturers of Transformers, Reactors and Rectifiers for Electronic and Power Transmission

LOOK FOR THE STACKPOLE MINUTE MAN... your guarantee of the highest in molded materials quality. ▶

STACKPOLE ALNICO II

Real Economy for Small Sizes—Better Uniformity—Greater Strength

*Stackpole Sintered Alnico II offers notable advantages in the molding of small magnetic components in weights up to two ounces and in almost any shape. Let Stackpole engineers investigate your requirements.

*Licensed under G-E patents

CARBON BRAZING TIPS

THAT LAST 4 TIMES AS LONG

Cut resistance welding or brazing costs! On a typical elevated temperature job where ordinary carbons were changed hourly, Stackpole Carbons processed with the famous anti-oxidation "F" treatment lasted all day. Three to four times longer life on the average job is an extremely conservative estimate of the saving involved—and they require dressing only about one-third as often! WRITE FOR SAMPLES. State shape and size required. Mention company connection.

THESE SILVER-GRAPHITE CONTACTS ARE 30% HARDER

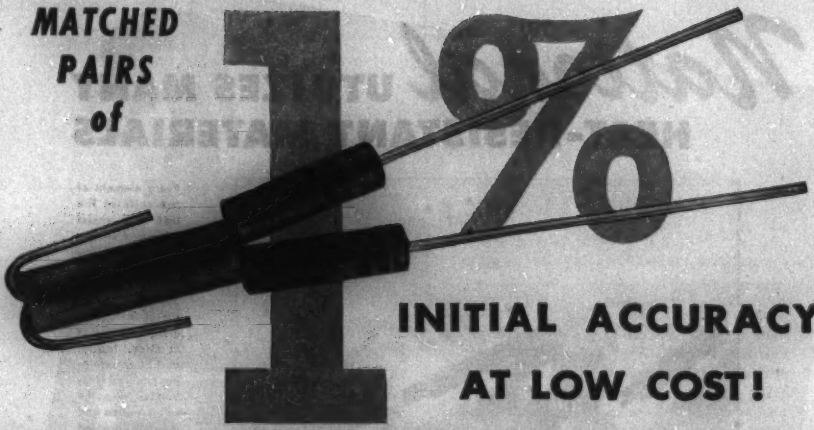
30% harder than conventional Silver-Graphite Contacts, but with no change in the composition of its ingredients, this new Stackpole material greatly prolongs life under short circuit conditions, assures far better contact drop, and improves wearing qualities tremendously. Ideal for a wide variety of circuit breaker, contactor and relay uses.

STACKPOLE

STACKPOLE CARBON COMPANY
St. Marys, Pa.

BRUSHES AND CONTACTS FOR ELECTRICAL EQUIPMENT
BRAZING TIPS, WELDING CARBONS, CHEMICAL CARBONS, PUMP & METERING SEALS, SPECIAL CARBON PRODUCTS

MATCHED PAIRS of 1%



INITIAL ACCURACY AT LOW COST!

Here's the low cost solution to close tolerance requirements—IRC Matched Pairs—two resistors matched in series or parallel to as close as ±1% initial accuracy.

IRC introduced Matched Pairs, has matched millions of BT Metallized and BW Wire Wound Resistors. Both types are stable, excellent for close tolerance requirements. Matched Pairs are widely used as meter multipliers and recommended for any application requiring low cost close initial tolerances.

IRC tests, matches, identifies, and ties together each pair as shown in the illustration above.

MATCHED PAIR RESISTANCE LIMITS

Type	Parallel Matched Pairs Minimum Resistance	Parallel Matched Pairs Maximum Resistance	Series Matched Pairs Minimum Resistance	Series Matched Pairs Maximum Resistance
BW-½	5 Ohms	410 Ohms	20 Ohms	1640 Ohms
BW-1	2.5 Ohms	2550 Ohms	10 Ohms	10,200 Ohms
BW-2	3.75 Ohms	4100 Ohms	15 Ohms	16,400 Ohms
BTS	235 Ohms	10.0 Megohms	940 Ohms	40.0 Megohms
BTA	165 Ohms	10.0 Megohms	660 Ohms	40.0 Megohms
BT-2	235 Ohms	10.0 Megohms	940 Ohms	40.0 Megohms

Matched Pairs are available only to manufacturers. Address inquiries to Dept. 51

PIONEERED FOR PERFORMANCE
IRC
FIXED & VARIABLE RESISTORS
Matched Pair Resistors
INTERNATIONAL RESISTANCE CO.
401 N. BROAD ST., PHILADELPHIA 8, PA.
Canadian Licensee: International Resistance Co., Ltd., Toronto

National UTILIZES MANY HEAT-RESISTANT MATERIALS

Every element of the coils at the left will resist damage from abnormally high operating temperatures—as high as 500° F. Collars are of Melamine, ground insulation is Mica, taping and block retaining material is Fiberglas and the coil is sealed and moisture-proofed with DC-993 Silicone varnish.

MELAMINE

During the war, Melamine resin-bonded Fiberglas laminated sheets proved themselves: very high heat and dielectric properties, resistance to fungus growth, low moisture absorption, dimensional stability. Special equipment is required to cut and machine it properly and economically. We have the equipment and the "know-how."

SILICONE

We were among the first to utilize the very high heat-resistant properties of the Silicones. All Silicones are not alike; there are Silicone rubbers, greases, moulding compounds, fluids and varnishes. Long experience has shown us how to handle them to retain maximum dielectric, moisture and acid resistance and other values.

FIBERGLAS

The heat-resistant properties of Fiberglas are well known, yet only recently has the development of heat-resistant varnishes and rigid sheets made possible taking greater advantage of those properties. Now we can produce coils whose heat-resistance is not threatened by the inclusion of a single bit of low temperature material. The ability of an electric coil to resist damage from high operating temperatures is only as strong as the least heat-resistant essential element used.

MICA

We have used Mica for many years to minimize heat-damage. We have combined it with many other materials to attain differing qualities, including our well-known trademarked Mica and Fiberglas combination, "Mica-Glas." Thoroughly experienced knowledge of the properties of Mica enables us to take full advantage of them and to use them in combination with other heat-resistant materials for complete high-temperature stability and high dielectric and mechanical strength.

our nearby Field Engineer is quickly available

NATIONAL ELECTRIC COIL COMPANY

COLUMBUS 16, OHIO, U. S. A.

ELECTRICAL ENGINEERS; MAKERS OF ELECTRICAL COILS AND INSULATION—REBUILDING AND REPAIRING OF ROTATING ELECTRICAL MACHINES

"Must be somethin' he et!..."

THERE'S ALWAYS A GOOD REASON why one kid shoots up faster than all the others in the neighborhood. It isn't luck. Most likely, it's more vitamins, more sunshine and better care.

Companies like Cornell-Dubilier don't grow up overnight either. Experts like C-D engineers don't just "happen". Only here it isn't what you *eat* or *dream;* it's what you *do*. You dig behind what others have told you. That's research. You look beyond what others have seen. That's pioneering. You spend more time and money, than might seem immediately profitable, to become proficient in your field. And when the "unheard of" has to be done, industry expects you to do it.

When giant capacitors, that could handle severe temperatures without the use of water-cooling coils, were needed, they came to Cornell-Dubilier. And when capacitors were needed for the Proximity Fuze, in sizes so tiny they had never before been envisioned, C-D engineers were handed the problem.

Remember that when your plans call for the unusual in capacitor design and dependability.

★ ★ ★

Cornell-Dubilier Electric Corp., South Plainfield, New Jersey. Five other plants in New Bedford, Brookline, Worcester, Mass. and Providence.

CD

CORNELL-DUBILIER

world's largest manufacturer of

CAPACITORS

MICA • DYKANOL • PAPER • ELECTROLYTICS

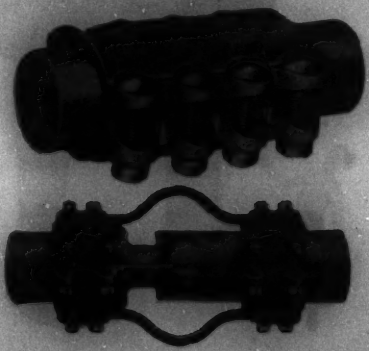
When You EXPAND

Modernize your electric buses with

BURNDY

POWER CONNECTORS and EXPANSION JOINTS

• For complete information on all the types, sizes and other specifications, consult the Burndy representative in your vicinity, or write for catalog 40.



BURNDY ENGINEERING CO., INC., 197-E Bruckner Blvd., New York 54, N. Y.

Because of the basic importance of adequate wiring to the entire electrical industry, Anaconda is presenting messages like this in a wide list of national publications

Wire ahead FOR FULL PRODUCTION

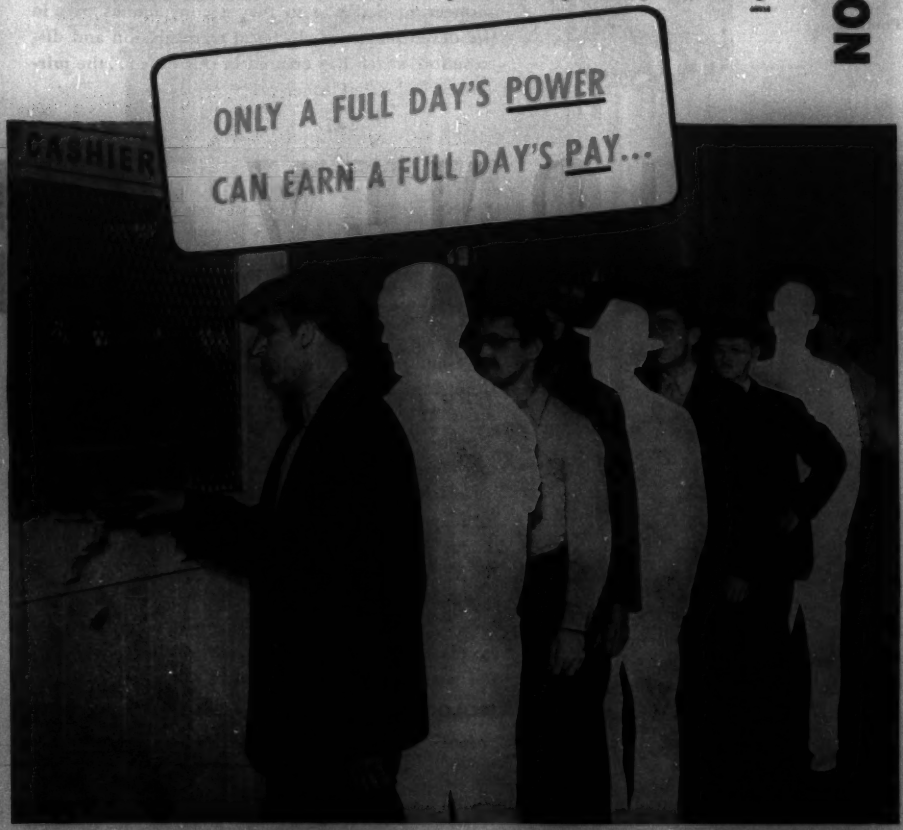
WHEN ELECTRIC POWER costs so little... and other costs are rising, no management can afford to overlook adequate wiring.

Obsolete wiring, overtaxed wiring can reduce machine efficiency, and hence worker efficiency, from 25 to 50 per cent.

For, when power fails, the productivity of the most ambitious, the most conscientious, the most skilled workmen you have must drop accordingly.

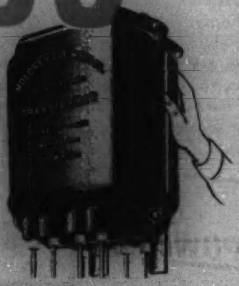
Talk over your wiring problem *now* with your plant power engineer, your consulting engineer, electrical contractor or power salesman. It may save expensive alterations later.

These men *know*, as you suspect, that postwar production depends on postwar wiring.



ANACONDA WIRE & CABLE COMPANY

1896



1896 Model,
5 Kw, Air-Cooled
Transformer

IN 1886 the first alternating current plant . . . with transformers and parallel distribution . . . was built in America. Just ten years later, the Moloney Electric Company was organized. Moloney was thus one of the early pioneers in the manufacture of transformers. In 1896 the founders of the Moloney Company had developed and marketed their new Core Type Transformer, the type that was destined to revolutionize the making of transformers. But this was only the beginning of Moloney pioneering . . . pioneering that was to play a conspicuous part in the development of electrical transmission and distribution which has created in our time . . . the miracle of Industrial America.

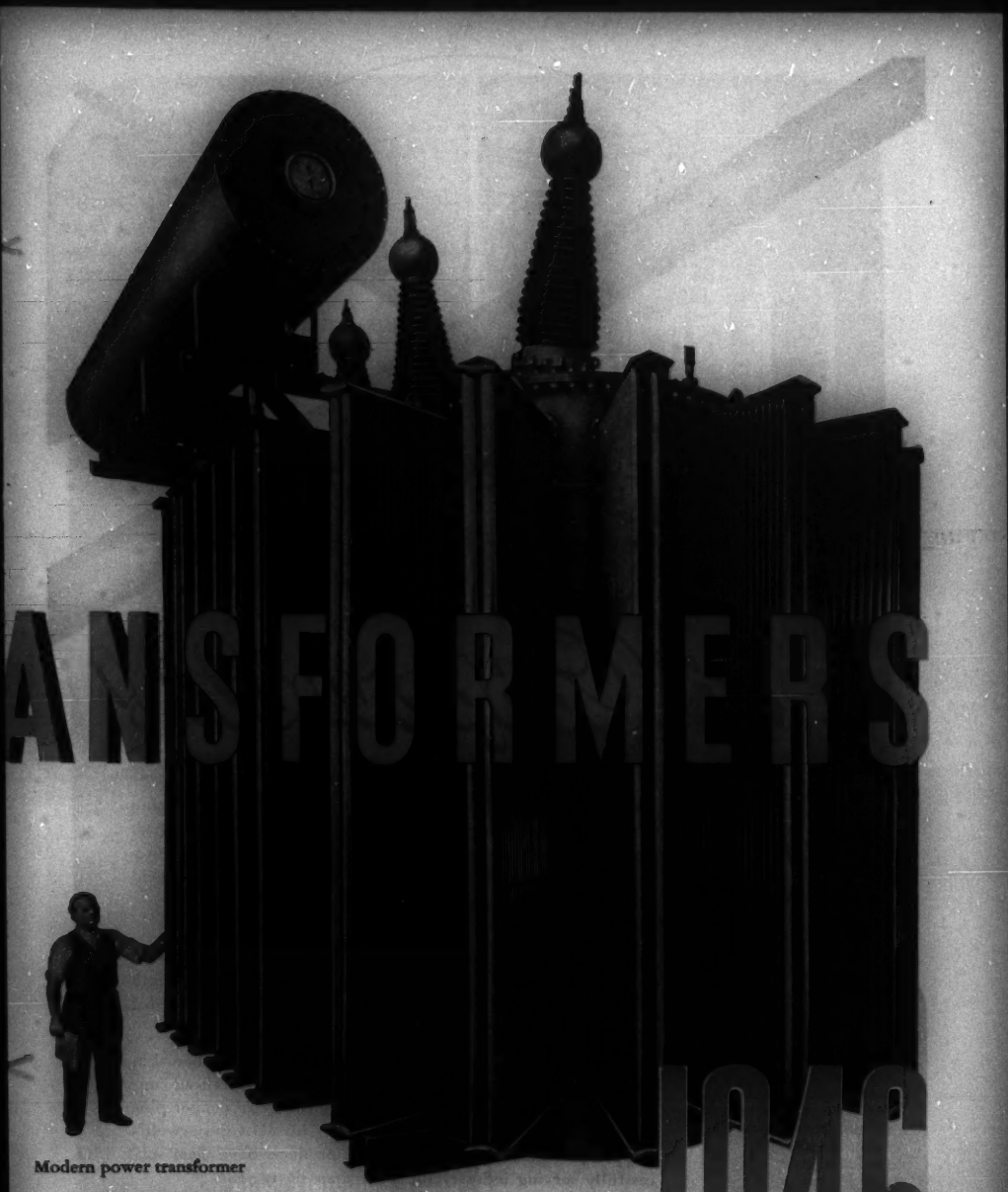
MOLONEY TR

50 eventful years have brought to Moloney Electric Company an enviable record of pioneering achievement. After developing the Core Type Transformer, Moloney was first in this country to commercially introduce the use of Silicon steel in cores. Another far-reaching Moloney development was the successful adaptation of the three-wire core type transformer. Today Moloney Transformers are known throughout the world for . . . unexcelled design . . . careful workmanship . . . trouble-free operation. Moloney, today, as in 1896, devotes its entire facilities, both in manufacturing and research, exclusively to the production of . . . transformers.

MOLONEY ELECTRIC CO. • ST. LOUIS 20, MO.

leadership in ENGINEERING

POWER AND DISTRIBUTION TRANSFORMERS



Modern power transformer

DESIGN • RESEARCH

EXCLUSIVELY SINCE 1896

ITS PROTECTION is more than skin deep

...it's Copperweld!

Only Copperweld-Copper gives you all these advantages
Copperweld is the only wire made by the proved MOLTEN-WELDING process

Copperweld wire does not depend for protection upon a thin deposit that temporarily coats the steel core, but upon a thick covering of copper, the molecules of which are permanently welded to those of the alloy steel by the exclusive Copperweld molten-welding process. The cut-away section above illustrates this point.

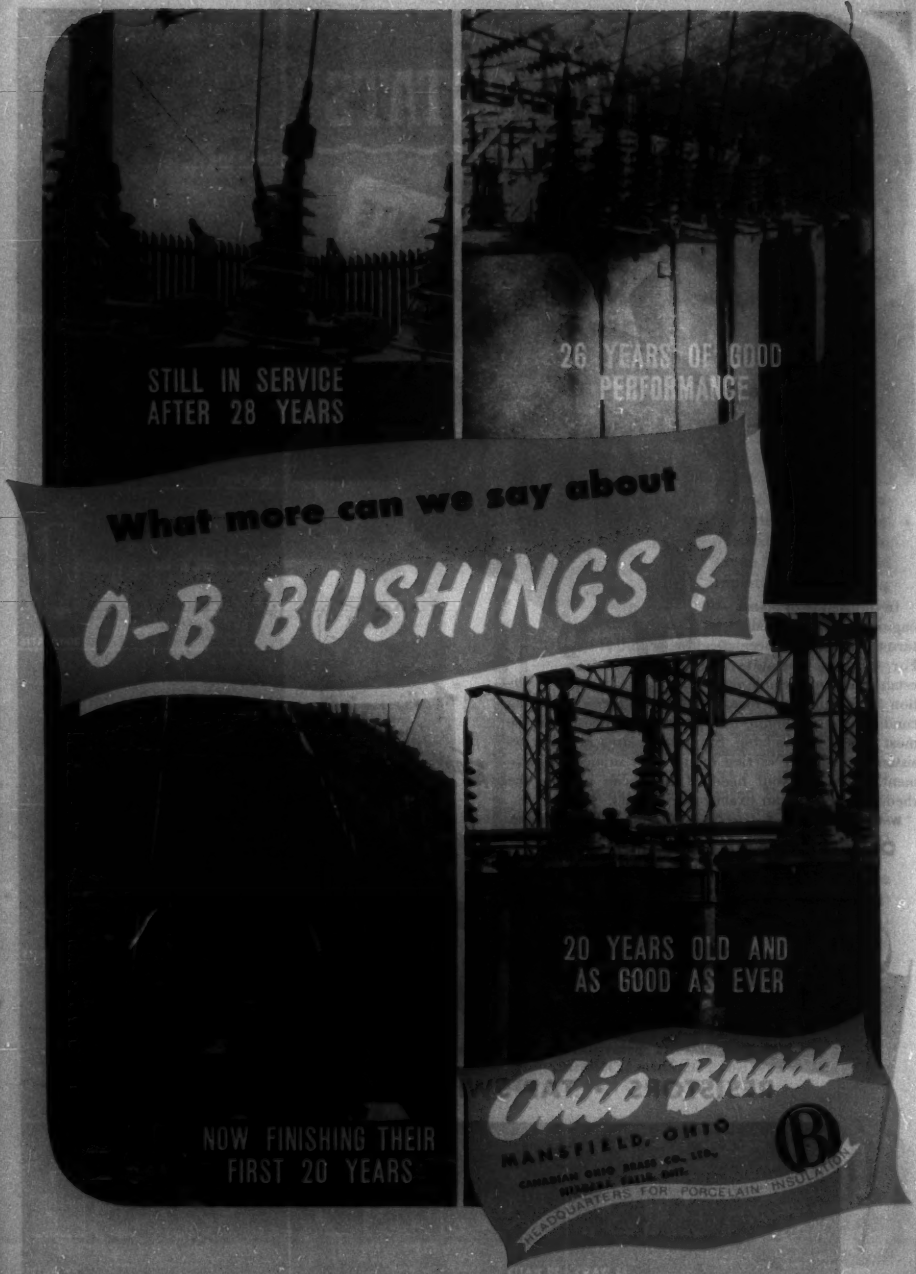
In addition to life-long protection against corrosion, Copperweld gives you excellent conductivity plus that high degree of strength necessary for long span construction and the ruggedness needed to withstand winds, ice and falling trees.

Yes—the protection afforded by Copperweld is "more than skin deep"— it really lasts! So, wherever you need an overhead conductor with the conductivity and rust-resistance of copper plus the rugged strength of steel, play safe—install Copperweld-Copper. Remember that Copperweld products have been successfully serving industry for more than thirty years.

Engineering data sent on request.

COPPERWELD STEEL COMPANY

GLASSPORT, PA. ***Sales Offices in Principal Cities***


STILL IN SERVICE
AFTER 28 YEARS
26 YEARS OF GOOD
PERFORMANCE
What more can we say about
O-B BUSHINGS ?
20 YEARS OLD AND
AS GOOD AS EVER
NOW FINISHING THEIR
FIRST 20 YEARS
Ohio Brass
MANSFIELD, OHIO
CANADIAN OHIO BRASS CO., LTD.,
NIAGARA FALLS, ONT.
HEADQUARTERS FOR PORCELAIN INSULATORS

RHEOSTATS?

We use OHMITE of course!

In thousands of plants engineers automatically turn to Ohmite for rheostats. For Ohmite rheostats have established an enviable reputation for unfailing performance under adverse operating conditions. The Ohmite line of standard rheostats is the most extensive available. Six wattage sizes in many resistance values are carried in stock for immediate shipment. Whatever your needs, Ohmite can provide the rheostat to meet your exact requirements.

Write on company letterhead for Catalog and Engineering Manual No. 40.

OHMITE MANUFACTURING CO.
4802 Flournoy St., Chicago 44, U.S.A.

Ten standard sizes 25 to 1000 watts

Be Right with . . .

OHMITE

RHEOSTATS
RESISTORS • TAP SWITCHES

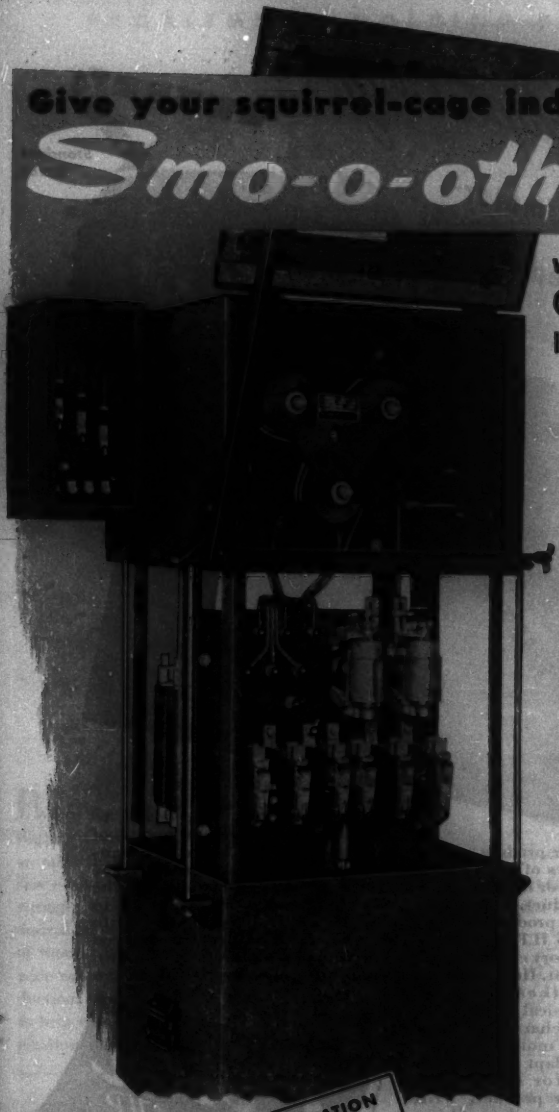
Give your squirrel-cage induction motors a

Smo-o-oth Start

with a ROWAN

OIL IMMERSED IMPEDANCE STARTER

(Type 900 Series)



This Rowan push button operated, fully automatic, reduced voltage starter of the impedance type, assures smooth starting with a minimum of line disturbance. It is a starter of the closed transition type utilizing for its acceleration, a combination of current and time. The acceleration period is dependent solely upon the driven equipment and load—thereby completely eliminating the human element. Continuous wound impedance coil assures freedom from tap failures—impedance is adjustable to each application. The unit is equipped with magnetic overload relays with automatic reset, providing a combination of inverse time element and instantaneous operation and single phase protection. Short circuit protection is afforded by time-tested Rowan Air-Seal fuses. It has a sealed-off, centralized wiring compartment for load line and control leads and provision for straight thru conduits. Enclosure is of the weather-resistant, dust-tight type. All electrical operating parts are oil immersed and the tank is mechanically interlocked to prevent lowering of the tank when the safety switch is in the "ON" position, or closing the switch when the tank is lowered.

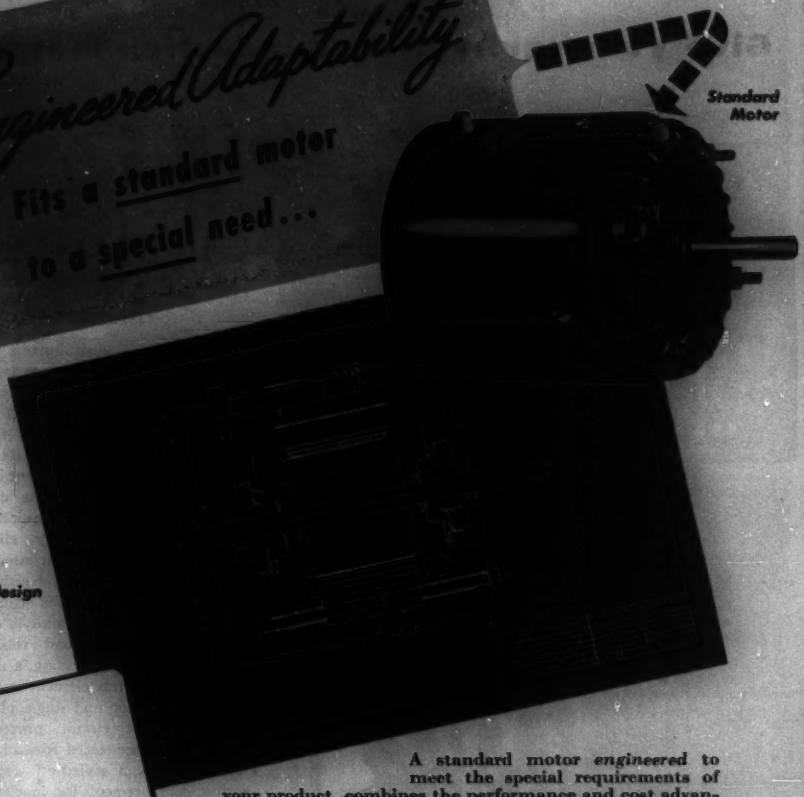
Illustrated circular containing complete details is available upon request.

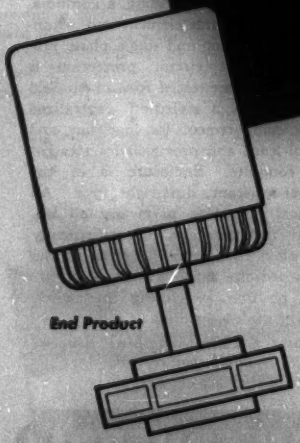
TYPE 900 KBF COMBINATION
Reduced Voltage Starter of the Impedance Type for use on 3 ph., 600 V service or less. Also available in 950 series for 2300 V., 3 ph., service.

ROWAN CONTROL
THE ROWAN CONTROLLER CO., BALTIMORE, MD.

Engineered Adaptability

Fits a standard motor to a special need...





A standard motor *engineered* to meet the special requirements of your product, combines the performance and cost advantages of both a standard motor and a special motor. The motor is not just added to the product; it is built into the product. Consult with our engineers NOW if you plan to use production-run quantities of small motors (1/500 to 1/15 H.P.) in your 1947 products. A skilled, experienced factory engineer will meet with your engineers in your own plant. He'll make a thorough study of your product design. He'll *engineer* the physical and electrical characteristics of the motor you need —adapt a standard motor *specially* to your product. Write today, describing briefly your product design plans.

Pilot Fractional H.P. MOTORS & BLOWERS

F. A. SMITH MANUFACTURING CO., INC.
450 DAVIS STREET ROCHESTER 2, N. Y.

FASCO

A MASTERPIECE IN PLASTICS

Before the war the Willard Storage Battery Company saw in polystyrene an opportunity to create a new battery case—transparent, acid-resistant, lighter than glass, stronger than hard rubber and readily molded to the desired shape and dimensions. During the war, hundreds of thousands of plastics battery cases were made for a wide variety of military purposes. For peacetime production, General Electric was called upon by Willard to help supply their demands for battery containers of plastics materials.

LEAKPROOF SEAL

The use of a specially prepared solvent permits the cover of the battery to be *permanently bonded* to the case. The seal is positively leakproof. It is not necessary to use a gasket.

G-E engineers, who use all kinds of plastic materials, are ready to help work out your plastics design problems. Consult G.E.'s complete plastics service for an unbiased material specification.

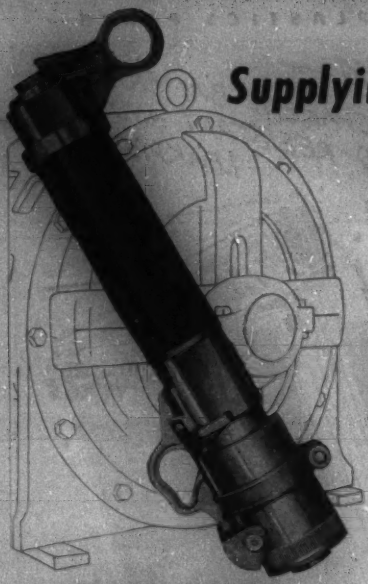
MOLDED-IN GAUGE

The plastics hydrometer shows at a glance when recharging is necessary. Small floating balls tell the story.

Bring your plans to General Electric—the world's largest manufacturer of finished plastics parts. "Designing Molded Plastics Parts," a helpful booklet, will be sent to you on request. Write Section E-8, Plastics Divisions, Chemical Department, General Electric Co., 1 Plastics Avenue, Pittsfield, Massachusetts.

GENERAL ELECTRIC

EVERYTHING IN PLASTICS



Supplying Adequate Protection for HIGH VOLTAGE polyphase MOTORS

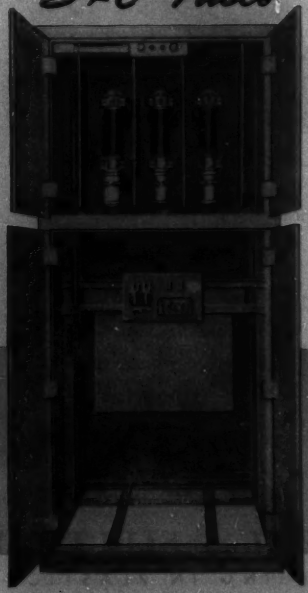
Where high voltage motors are employed there is likely to be a high concentration of power, and consequently severe short circuit conditions. The requirements of such installations urge the application of S & C Type S M Power Fuses, for adequate short circuit protection.

Type S M Fuses in one form have the high interrupting capacity required to provide protection where short circuits up to 40,000 r.m.s. amperes might occur. This high interrupting capacity results from a boric acid arc extinguisher of proper design.

Confining the arc within the fuse, S & C Type S M Fuses with condensers often result in important economy of space in cubicles and cell structures. They have highly accurate fusible elements which retain their accuracy under all conditions. Blown fuses may be restored to service by the simple replacement of an inexpensive refill unit.

S & C Type S M Fuses are made for various applications, 2,300 to 138,000 volts and 1 to 400 amperes. Bulletin 242 covers high voltage motor applications. Ask for it today.

Type S M
(BORIC ACID)
S & C Fuses



SCHWEITZER & CONRAD, INC.
4427 Ravenswood Avenue — Chicago 40, Illinois, U.S.A.

Represented in Principal Cities (Consult Telephone Directory)
In Canada by Powerlite Devices, Ltd., Toronto, Canada

In the typical motor starter application shown at the left, S & C Type S M Fuses provide adequate and economical short circuit protection while oil-immersed contactors and overload relays supply the overload protection.

As revealed here, Type S M Fuses and Condensers require a minimum of space when housed in a steel cubicle. They are of the disconnect type, and may be handled with a hook stick.

"Experience will choose an S & C Fuse"

FTR 9-A-1 CARRIER TELEPHONE SYSTEM

An ADDITIONAL TELEPHONE CHANNEL

OVER EXISTING OPEN-WIRE LINES AND CABLES

Telephone companies, railroads, power, oil, pipe-line and other companies having privately-owned communication lines will find the FTR 9-A-1 Carrier Telephone System indispensable for additional telecommunication facilities... permanent or temporary... without need of outside plant expenditures.

This Single Channel Carrier Telephone System provides high-grade communication over 300 miles... with intermediate repeaters it is applicable on lines 1,000 miles or more, depending on the gauge of open wire conductors, length of intermediate cables and number of bridged stations. The FTR 9-A-1 features interchangeable terminals, two or four wire termination, built-in ringer. Write to Dept. H 515 for complete details.

Available Now!

COMPACTNESS | ACCESSIBILITY | FLEXIBILITY | SEALED UNITS | EASILY INSTALLED

Federal Telephone and Radio Corporation

In Canada:—Federal Electric Manufacturing Company, Ltd., Montreal
Export Distributor—International Standard Electric Corporation

Newark 1, New Jersey

A New Carbonyl Iron Powder..."HP"

...NOW RELEASED FOR CIVILIAN APPLICATIONS

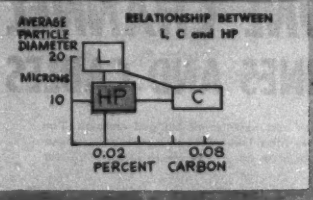
CARBONYL Iron Powder "HP" made it possible to bring bomber loop antennas inboard.

Why? Because an *extra* step in the carbonyl process greatly reduces the size of the particles and minimizes the impurities. At frequencies up to several megacycles —magnetic coils from "HP" powder combine *high* permeability with *low* losses.

High "Q" values and high permeability offered by Carbonyl Iron Powder "HP" make its application to *permeability tuning* outstanding.

Check your requirements against these basic features of Carbonyl Iron Powder "HP."

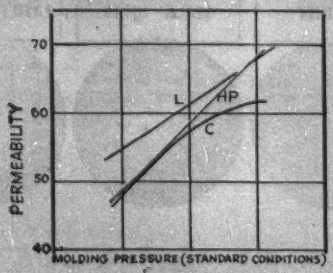
HOW DOES "HP" DIFFER PHYSICALLY?

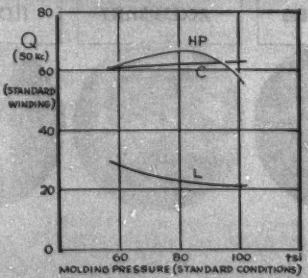


Carbonyl Iron Powder Grade	Average Diameter (microns)	Carbon Content %
HP	10	.01 - .03
L	20	.005 - .03
C	10	.03 - .12

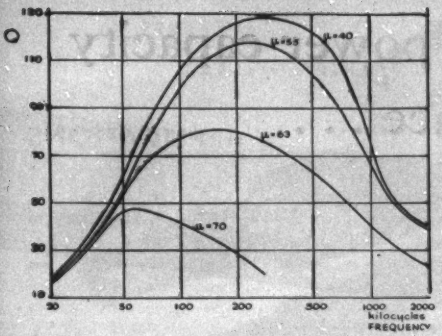
1. "HP" powder has a smaller particle size than Carbonyl Iron Powder "L"—a higher degree of purity than Carbonyl Iron Powder "C." (Note, however, that possibly "HP" will show no superiority over a "C" powder core in many cores of high dilution or insulation content.)

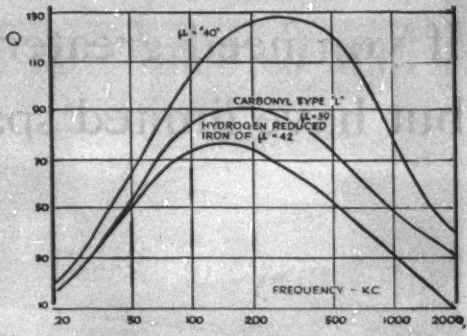
HOW DOES "HP" DIFFER ELECTROMAGNETICALLY?



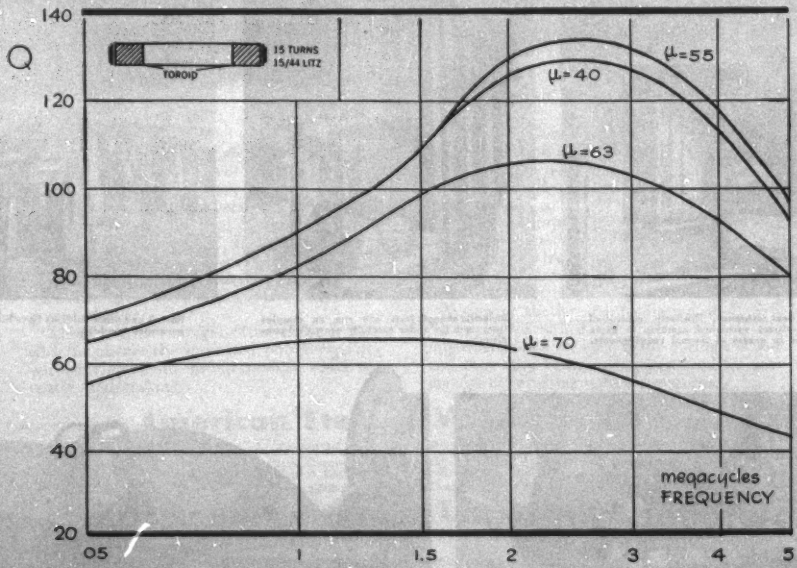


2. "HP" powder has distinct advantages in permeability and "Q" value (plotted against molding pressure). For comparative purposes, toroid core curves for Carbonyl Iron Powders "L" and "C" are shown against "HP."





3. These curves show "Q" values versus frequency for several "HP" and comparison toroid cores. Even at relatively high frequencies, working permeabilities up to 70 can be obtained with reasonable "Q" values.



4. "HP" powder has superiority in cylindrical winding, as illustrated by this curve.

Particular requirements can be met by applications of Carbonyl Iron Powder "HP." Additional specific information and technical data are available without obligation.

Write or wire collect: Special Products Sales Division, General Aniline & Film Corporation, 270 Park Avenue, New York 17, N. Y.

G.A.F. CARBONYL IRON POWDERS

If you need greater power capacity but have limited space . . .

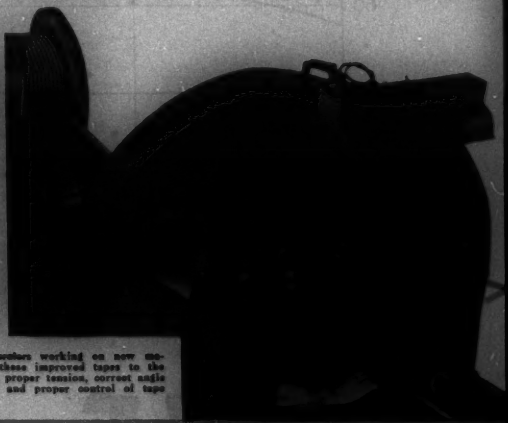
Use these improved U·S·S American Varnished

Greater heat resistance. Precisely controlled ovens subject varnished cambric to aging tests far in excess of normal requirements.

Dielectric strength tests are run on samples from each lot under carefully controlled conditions.

Hot oil and other solvents have little effect on varnished cambric.

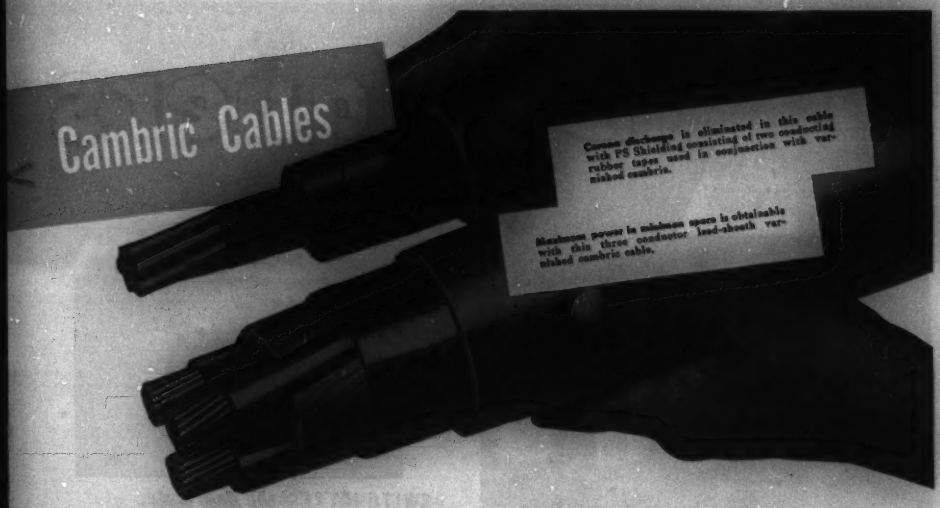
Tearing strength, ounce and thread count are determined to maintain high standards of quality.



Experienced operators working on new machines apply these improved tapes to the cable assuring proper tension, correct angle of application and proper control of tape position.

Types of Varnished Cambric Cables

- Single-conductor series street lighting cables.
- Multiple-conductor non-leaded and unarmored cables.
- Control cables with combination of different colored braids.
- Single-conductor lead-sheathed cables.
- Single-conductor non-leaded cables.
- Multiple-conductor lead-sheathed or metallic-armored cables.


Cambric Cables
Corona discharge is eliminated in this cable with PS Shielding consisting of two conducting rubber tapes used in conjunction with varnished cambric.
Maximum power in minimum space is obtainable with this three conductor lead-sheath varnished cambric cable.

ENGINEERS who are faced with increasing the capacity of their power lines but are limited by conduit size will get help from the improved U·S·S Varnished Cambric Cables.

Higher operating temperatures can be used as the improved varnished cambric will stand temperatures up to 85°C. In this respect it is notably superior to rubber. It is also superior in dielectric strength so that thinner walls of varnished cambric insulation can be used for a given voltage.

These two advantages often make it possible to obtain the increased power capacity without ripping out the old conduits which is a costly undertaking.

Varnished Cambric Cable may be obtained with over-all braids, lead sheath, or Ampyrol synthetic resin non-metallic jackets. Type PS Shielding employing non-metallic conducting tapes over the conductors and over the insulation offers improved high-voltage operation.

Another important advantage is that they are not injured by oil, grease, or corona so they can be used around all types of machinery without danger of disintegration.

Write for the latest information on U·S·S American Varnished Cambric Cables. Great improvements have been made during the war and they may be just what you need for new layouts or re-wiring your old systems.

American Steel & Wire Company

Cleveland, Chicago and New York

Columbia Steel Company, San Francisco, *Pacific Coast Distributors*
Tennessee Coal, Iron & Railroad Company, Birmingham, *Southern Distributors*
United States Steel Export Company, New York

UNITED STATES STEEL

Where to use U·S·S American Varnished Cambric Cables

IN MODERATE OR LOW-VOLTAGE INSTALLATIONS where its superior heat resistance permits greater current carrying capacity for a given copper area.

IN POWER PLANTS for general wiring and such applications as insulated bus bars, motor and generator leads, connections for oil switches, transformers and voltage regulators.

IN INDUSTRIAL PLANTS, especially where heavy loads must be transmitted for short distances.

AMERICAN STEEL & WIRE COMPANY — U·S·S — AMERICAN ELECTRICAL WIRE AND CABLE — UNITED STATES STEEL

U·S·S American Varnished Cambric Cables

ELECTRONICS

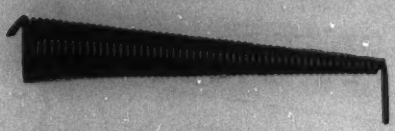
Designers

NEW PYRANOL* CAPACITORS

new sizes, new quality

Strict quality control, new manufacturing techniques, and improved materials — the basis of the excellent war-time records of G-E d-c capacitors — are now incorporated in a new line of Pyranol capacitors designed to meet rigorous commercial requirements.

This new line makes possible a broad selection of sizes, ratings and mounting arrangements, with characteristics which permit operation over a wide temperature range (from 85C to —55C), at altitudes up to 7,500 feet. Sizes and shapes range from "bathtub" and small rectangular case styles to large, welded steel-case designs. Capacitance ratings are offered from .01 muf to 100 muf, and voltage ratings from 100 to 100,000 volts. Write *Transformer Division, General Electric Co., Pittsfield, Mass.*



MORE COMPACT COILS

wound faster

Formex* magnet wire, available in all standard wire sizes, puts more turns and more copper in a given coil cross-section area than fibrous-covered wire does, particularly if square or rectangular Formex wire is used. It's a natural where coil shapes require acute angle bends. Higher winding speeds are practical without increasing rejects; time-saving steps are possible that you wouldn't dare use with ordinary magnet wire. In most sizes, first cost of Formex is less than fibrous-covered wire, and only slightly greater than enameled. Check Bulletin GEA-3911.

*Reg. U.S. Pat. Off.

SWITCHETTES *do big jobs in cramped quarters*

G-E manually-operated Switchettes are outstanding for the long life and lightning-fast snap action packed into an unusually small, lightweight case. The Size 1 Switchette weighs only 9 grams, and is approximately 1¼ in. by ½ in. by ⅓ in. Size 1 Switchettes are available in ratings up to 10 amperes at 24 volts d-c, or 230 volts a-c, and in ten different contact arrangements. Size 2 Switchettes are rated 25 amperes at 24 volts d-c, (230 volts a-c), and are available in three contact arrangements: single circuit, normally open; single circuit, normally closed; and two circuit. Totally enclosed, with screw terminals, size 2 Switchettes measure about 2 by 1⅝ by 1 inch, and weigh approximately 2 ounces. Write for Bulletin GEA-3818C (Size 1) or GEA-4259 (Size 2).

A VERSATILE SWITCH

with 4,000 possibilities

There's a *standard* SB-1 switch for most of the ordinary control and transfer jobs. Where the number or arrangement of circuits is unusual, special switches can be made from standard SB-1 cams, contacts, fingers, and other parts, giving great flexibility of application. Precision-built parts make even a 40-stage tandem switch easy to operate.

Already more than 4,000 different arrangements of circuits and sequences have been made by varying contacts and cam arrangements. Others can be made to meet your specifications. Write for Bulletin GEA-1631E.

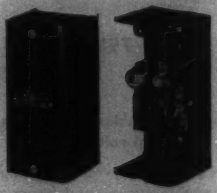
Digest

TIMELY HIGHLIGHTS ON G-E COMPONENTS

SMALL DC METERS

that are lighted two ways

General Electric Type DO-58 d-c meters are 4 by 4½ inches. Voltmeters are available registering from 0 to 1 volt, to 0 to 750 volts in self-contained models, and up to 30 kv with external resistors. Accuracy is to within 2 per cent of full scale value. The d-c ammeters, milliammeters and microammeters cover a range from 0 to 50 amperes, to 0 to 50 microamperes. Cased in black Textolite with a deep cover, these meters are offered in front-illuminated and rear-illuminated types, with lance type, pointer-tip standard, and knife-edge and pear-shaped tips optional. These flush-mounted instruments are also available in alternating-current, a-c rectifier and r-f types. Write for Bulletin GEA-4272.



INDUSTRIAL RELAY *does a lot of jobs*

This sturdy, compact industrial voltage relay has a lot of uses, such as controlling pilot circuits in response to remote control switches or thermostats, or for direct control of small motors driving cooling blowers. It may be used as a fractional-horsepower motor starter, or in conjunction with magnetic switches controlling larger apparatus. Rated 10 amperes, continuous, with make-or-break rating of 45 amperes on normally open poles, 20 amperes on normally closed poles, at either 110 v or 220 v a-c. Three contact arrangements — double-pole, double-throw; double-pole, single-throw; and single-pole, single-throw — are available in either open or enclosed models. Write for Bulletin GEA-4668.

SPLIT-CYCLE CONTROL

of heavy currents

Thyratron Type FG-95 tubes are designed for rapid control applications where available grid power is very small, where it is necessary to actuate the grid from a high-impedance source, and where tube temperature can be maintained at a relatively constant level. This tube's negative grid characteristics mean lower overall power requirements for heavy-duty control work. Peak voltage, 1000 v, peak current 15 amp, average current 2.5 amp. Surge current (for design only) 200 amp for 0.1 second.

Among the applications of Thyratron tubes are resistance welding control, motor control, lighting control, rectification, and power supply for photoelectric relays. Write for Bulletin ETI-125. (For general data on Thyratrons, ask for ETI-116). *General Electric Co., Electronics Division, Syracuse, N.Y.*

DURABLE NAMEPLATES

with beauty built-in

General Electric laminated plastic nameplates are tough, durable, and resistant to impact. They are available stamped, engraved, or printed, in a variety of color combinations. Their appearance is exceptional — both satin and mirror finishes are offered with surfaces that need neither buffing nor polishing. The hard, smooth surfaces of G-E plastic nameplates are easily cleaned. They do an outstanding job for a wide range of diversified applications. For further information, write *General Electric Co., Plastics Division, Pittsfield, Mass.*

GENERAL ELECTRIC COMPANY, Sec. 642-12
Apparatus Department, Schenectady 5, N. Y.

Please send me

.....GEA-1631E (SB-1 Switches)	.....GEA-3818C (Switchettes—Size 1)
.....GEA-3911 (Formex)	.....GEA-4259 (Switchettes—Size 2)
.....GEA-4272 (Small D-C Meters)	.....GEA-4668 (Industrial Relay)

NOTE: More data available in Sweets' File for Product Designers

Name_____

Company_____

Address_____

City_____ State_____

NEW!!

WESTON Mutual Conductance Tubechecker and Circuit Analyzer

MODEL 798—TYPE 3

Outstanding Features

- Direct-reading mutual conductance tests, and "Good-Bad" indications.
- New patented high frequency tube testing circuit.
- AC-DC volt-ohm-milliampere ranges.
- Tests 4, 5, 6, 7 prong octal, loctal, miniature, and acorn tubes.. spare octal and miniature sockets.
- Hot neon leakage test between any two tube elements . . . neon short check.
- Adjustable plate, screen, grid bias, and signal voltages.
- Flexibility in switching simplifies testing present and future tubes.
- Durable heavy-gauge, light-weight alumium case.

Model 798 combines broad utility, ruggedness, and dependable accuracy for maintenance of sound and electronic equipment. Detailed bulletin available. Weston Electrical Instrument Corporation, 664 Frelinghuysen Avenue, Newark 5, New Jersey.

Weston Instruments

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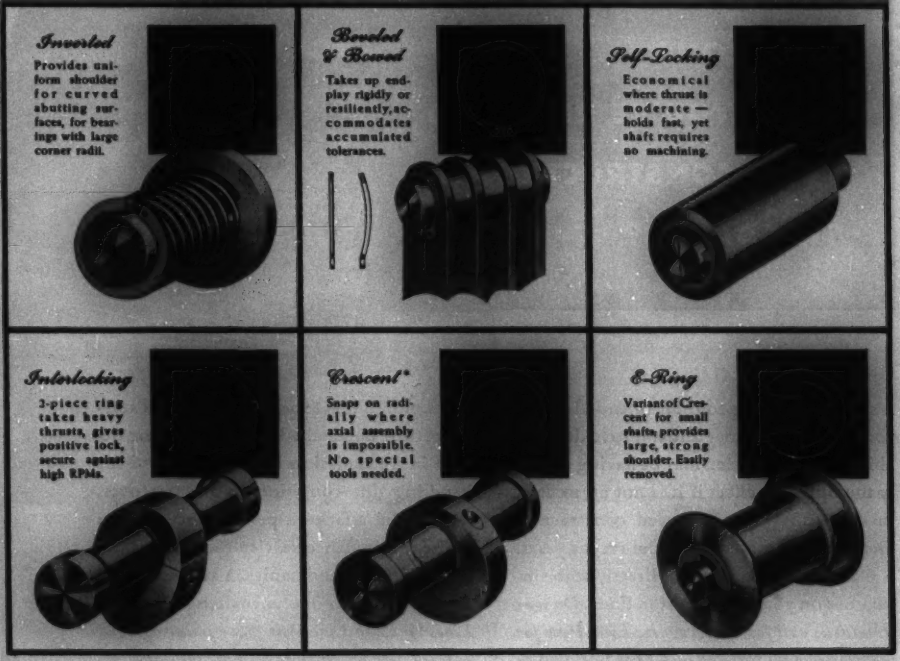
Precision fastening for any need: Waldes Truarc Special-Type Retaining Rings


Inverted
Provides uniform shoulder for curved abutting surfaces, for bearings with large corner radii.
Beveled & Bowed
Takes up end-play rigidly or resiliently, accommodates accumulated tolerances.
Self-Locking
Economical where thrust is moderate — holds fast, yet shaft requires no machining.
Interlocking
3-piece ring takes heavy thrusts, gives positive lock, secure against high RPMs.
Crescent*
Snaps on radially where axial assembly is impossible. No special tools needed.
E-Ring
Variant of Crescent for small shafts; provides large, strong shoulder. Easily removed.

● There's a Waldes Truarc precision-engineered ring to answer every need. Truarc Retaining Rings give a never-failing grip because of their mathematically precise construction. No matter how demanding your specifications, it's a simple matter to refine your present designs to save material, machining and assembly costs. Waldes Truarc engineers will help you, will give your particular problem individual attention without obligation.

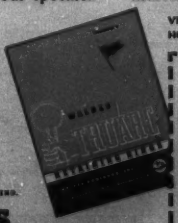
WALDES TRUARC

TRADE MARK U. S. PAT. NO. 19,144 AND OTHER PAT. PEND.

RETAINING RINGS

WALDES KOHINOOR, INC., LONG ISLAND CITY 1, NEW YORK

*U. S. PAT. 2,383,948



VISIT TRUARC BOOTH • INSTRUMENTATION-FOR-TOMORROW EXHIBIT
HOTEL WILLIAM PENN, PITTSBURGH • SEPTEMBER 16-20

Waldes Kohinoor, Inc., 47-10 Austel Place
Long Island City 1, N. Y., Dept. 16-F

Please send Catalog No. 4 on Truarc Retaining Rings to:

Name_____

Title_____

Company_____

Address_____

City_____ Zone____ State_____

A standardization program, intended to save your company money and improve dependability of your system, may be having directly the opposite effect if it is not up to date, incorporating the improved construction methods and materials of the recent years.

Our question is pointed directly at the insulators on your high tension lines. *Do your standards call for, or recognize Line Posts for transmission up through 66 Kv?* If not, you're inviting trouble and extra expense with every conductor you string.

The Lapp Line Post is now more than 15 years old. In that 15 years it's run up a service record unmatched by any insulator design in transmission history. A record for handling dirt conditions, power arcover, mechanical attack—a performance written in the maintenance service records of hundreds of power companies. A service record that adds up to one unchallengeable fact: *Lines on Lapp Line Posts have fewer outages, require less maintenance and insulator replacements than lines on any other insulators.*

Better get Lapp Line Posts on your standard specifications now.

Only a miniature,

but why not ALCOA ALUMINUM in the real towers?

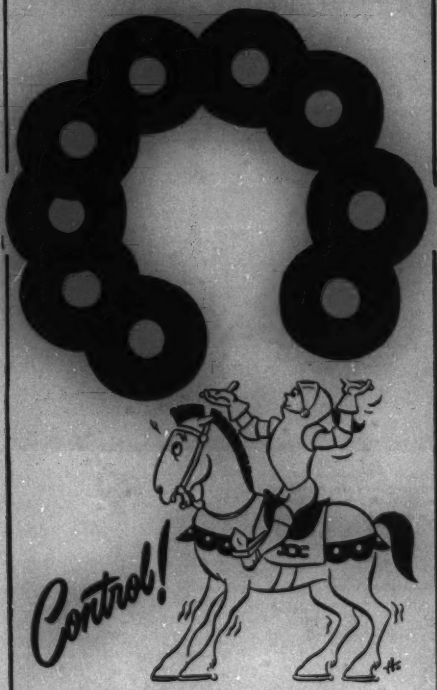
Aloca Aluminum structural shapes are being used for substations and switchyard structures, as crossarms on H-frame structures. Being highly resistant to corrosion, the aluminum needs no protective painting. That expense, costly shutdowns, and the maintenance hazard are all avoided.

Aluminum structural shapes are light in weight, easy to transport in rough country, easy to erect. Why couldn't Alcoa Aluminum structural shapes be used for transmission line towers in your power plant?

Alcoa Aluminum structural shapes are available for your shipment. Alcoa has the data your engineers will need to include aluminum in your structures. For [illegible] and prices, call the

ALCOA ALUMINUM

MORGANITE
Carbon Piles



The juggler's control is center of achievement if the objects being tossed are identical in every way.

His choice, in this case, is a happy one because "Link Control" is the guarantee that each piece is identical with its neighbor.

The "control" exercised at our mines, in the selection of raw material, is "linked" to the "control" practiced at each stage of manufacture. Each inspection is another link in the chain. With "Link Control" on the job you get every piece to exact specification.

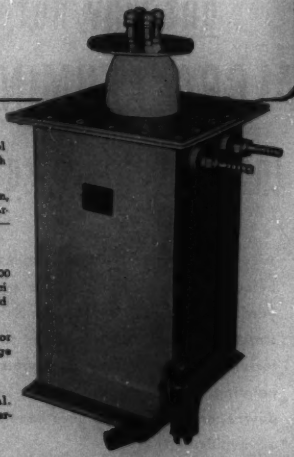
Use MORGANITE and know you're right.

MORGANITE
INCORPORATED
LONG ISLAND CITY 1 · NEW YORK

AEROVOX SERIES 1780

Water-cooled

MICA CAPACITORS



Mica stacks and cooling coils in oil bath

Air-cooled operation, 200 KVA, with water-cooling, 1000 KVA—a one-to-five ratio.

Ratings up to 25,000 v. A.C. Test. Capacitances up to .01 mfd

Lower power factor (.01%). Long life. Large factor of safety.

Four-stud terminal. Grounded case. Silver-plated hardware.

● This new water-cooled oil-filled mica capacitor handles exceptional KVA loads for its size. This means that more power can be handled than with previous capacitors of similar size or, conversely, capacitor size can be greatly reduced for given power ratings.

Series 1780 capacitors attain their higher KVA ratings in two ways: (1) By exceptional design such as critical arrangement and location of sections; choice of materials; specially-plated parts; large cross-section of conductors; careful attention to details and true craftsmanship in production. (2) By the use of a water-cooling system so designed as to provide maximum heat transfer from capacitor section to cooling coils.

All in all, a sturdy, compact, hard-working, trouble-free mica capacitor for extra-heavy-duty service such as induction furnaces and high-power transmitters.

● DATA ON REQUEST . . .

AEROVOX capacitors
FOR RADIO-ELECTRONIC AND INDUSTRIAL APPLICATIONS

Where Temperatures Run High

ASBESTOS BRAID RESISTS HEAT, MOISTURE, OIL, GREASE AND FLAME
VARNISHED CAMBRIC FOR HIGH DIELECTRIC STRENGTH
PERFECTLY CENTERED CONDUCTORS
OUTER ASBESTOS WALL WITHSTANDS HIGH AMBIENT TEMPERATURES
INNER FELTED ASBESTOS WALL TAKES CONDUCTOR HEATING OVERLOADS

ROCKBESTOS A.V.C. PREVENTS WIRE FAILURES AND REDUCES MAINTENANCE EXPENSE

Wherever you have boilers, steam tunnels, pump rooms, ash pits . . . you have circuits exposed to baking heat that takes the life out of most wire insulations and eventually causes failure. In hot spots like these, Rockbestos A.V.C. wires and cables will prevent failure . . . protect operations . . . and save you money in circuit maintenance.

Here's how. Their impregnated felted *asbestos* insulation and heavy *asbestos* braid resists heat and moisture, rotting fumes, oil, grease, oxidation and flame . . . permits continuous operation under temperatures up to 230°F . . . and gives you the safety factor of greater current carrying capacity.

If your circuits operate in high temperatures, you can practically eliminate wire-failures and circuit breakdowns by wiring new installations or rewiring trouble-makers with Rockbestos A.V.C. . . . the cable that is built to withstand heat and severe operating conditions.

Rockbestos A.V.C. and All-Asbestos wires and cables are available in 600 to 5000 volt ratings . . . single or multi-conductor . . . plain, lead sheath or armored constructions. Write for catalog and samples.

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The Wire with Permanent Insulation

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ROCKBESTOS A.V.C. 600 VOLT POWER CABLE-CODE TYPE AVA
(Max. operating temperature 230°F)

The cable illustrated and similar types rated up to 5000 volts assures trouble-free performance in hot locations with this construction:

- A tough impregnated asbestos yarn braid, resistant to heat, flame, moisture, oil, grease and corrosive fumes.
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- Inner wall of impregnated felted asbestos that withstands conductor-heating overloads and won't bake brittle or burn.
- The conductor is perfectly and permanently centered in helically applied non-flowing insulation that provides greater current carrying capacity.

One of the 185 different constructions designed by Rockbestos for severe or unusual operating conditions.

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You'll like the fact that circuit breaker units are interchangeable for same rating and type of breaker . . . and saving of aisle space by compact vertical lift construction. It all adds up to your greater convenience!

Get full details on metal-clad, vertical lift switchgear by contacting our nearby sales office. Or write directly to ALLIS-CHALMERS, MILWAUKEE 1, WIS.

☑ **Want Simple Installation?** You'll get it with completely factory-built, wired and assembled Allis-Chalmers switchgear units . . . easy to install, and more units can be added in the future without trouble. Lining up just four points — not eight — saves installation time!

☑ **Want Easy Maintenance?** Note these Allis-Chalmers metal-clad switchgear details: Removable plates for access to bus and instrument transformer compartments, circuit breaker, and secondary wiring; "hinged" wiring connection eliminates wear or bending on wires when door is opened or closed; special method of insulating busbars does away with using compound filling for bus joints.

☑ **Want Safe Operation?** You get that, too, when you specify Allis-Chalmers switchgear. Isolation of units, *fully automatic* disconnect shutters, and positive interlocks on elevating mechanism are a few of the details adding up to *safety* for operators!

A 2076

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METAL-CLAD *Switchgear*

HERE'S A *New Line* OF D-C CAPACITORS

BETTER IN "*Civvies*" FOR HAVING WON THEIR SERVICE STRIPES

It's an open secret among the trade that G-E Pyranol capacitors, which enjoyed such an enviable reputation before the war, are now better than ever!

The reasor for this is obvious. Some pretty tough demands had to be satisfied during the war. The strict quality control methods, new manufacturing techniques, and improved materials, instituted at that time have produced outstanding results which General Electric has now incorporated in a new line of Pyranol capacitors designed to meet commercial requirements.

This new listing makes available a wider range of sizes, ratings, and mounting arrangements with characteristics for operation over wider temperature ranges (−55°C to +85°C), at altitudes up to 7500 ft.

These G-E *Pyranol-treated fixed paper dielectric capacitors range in size and shape from bathtub and small rectangular case styles to large, welded steel case designs. Capacity ratings from .01 muf to 100 muf, and voltage ratings from 100 to 100,000 volts are listed. The high dielectric strength and stable characteristics of the special Pyranol-impregnated Kraft paper are hermetically sealed into these non-inflammable units, thus assuring long life.

*Pyranol is General Electric's non-inflammable liquid dielectric for capacitors.

D-C Capacitors

GENERAL ELECTRIC

SECTION E-407-108

GENERAL ELECTRIC COMPANY
Apparatus Department, Section E407-108
Schenectady 5, N. Y.

Gentlemen: Kindly send me further information on "Fixed Paper Dielectric Capacitors for DC Applications."

Name .....

Organization .....

Address .....

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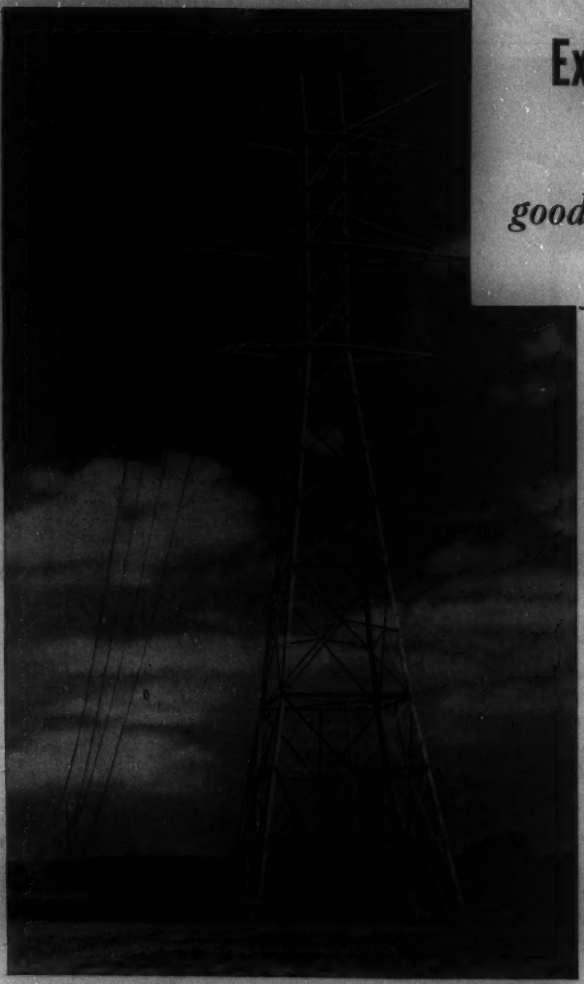

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means a good-looking tower

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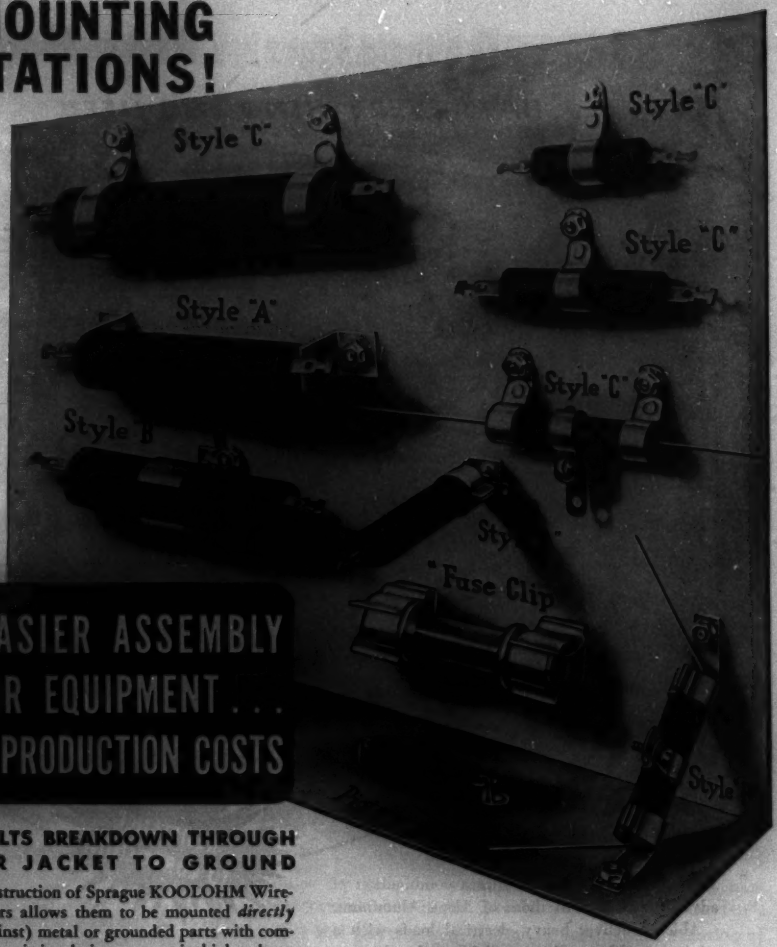

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SPRAGUE ELECTRIC COMPANY, Resistor Division, North Adams, Mass.

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Able to deliver heavy electrical loads with a minimum of loss—Sizes available to handle any electrical load—Highly resistant to corrosive atmospheres, indoors and out—Light in weight, easily formed, are convenient to install.

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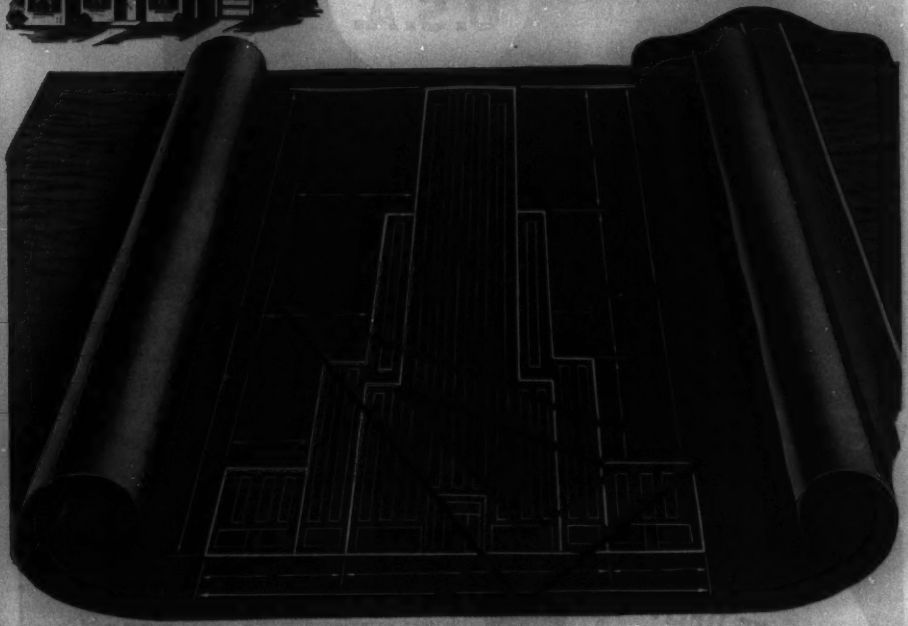

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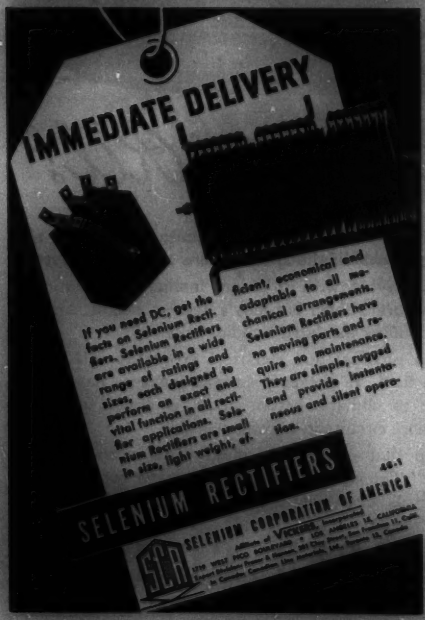
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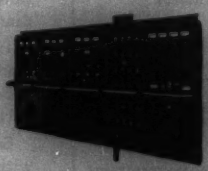

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Making important check tests of insulation resistance is a one-man job with any type of "Megger" Insulation Tester. For example, the illustration shows our Midget type being used for a periodic test on one of a group of fire-pump motors. After making connections, the operator merely turns the crank of the hand generator—and reads resistance directly on the scale. It is done as simply and quickly as the telling.

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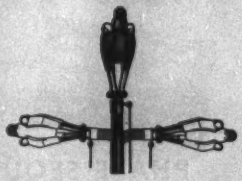
MATTHEWS HOLDFAST LAMP CHANGERS



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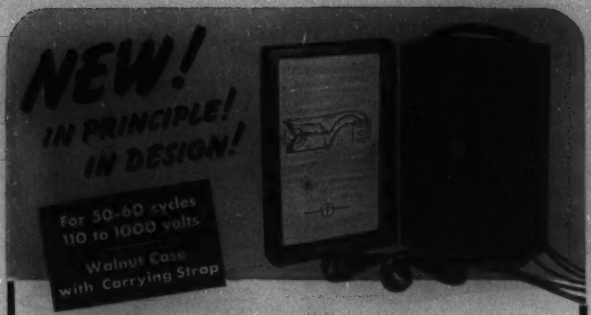

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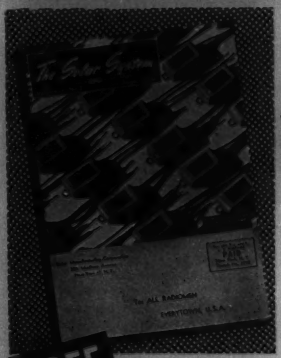

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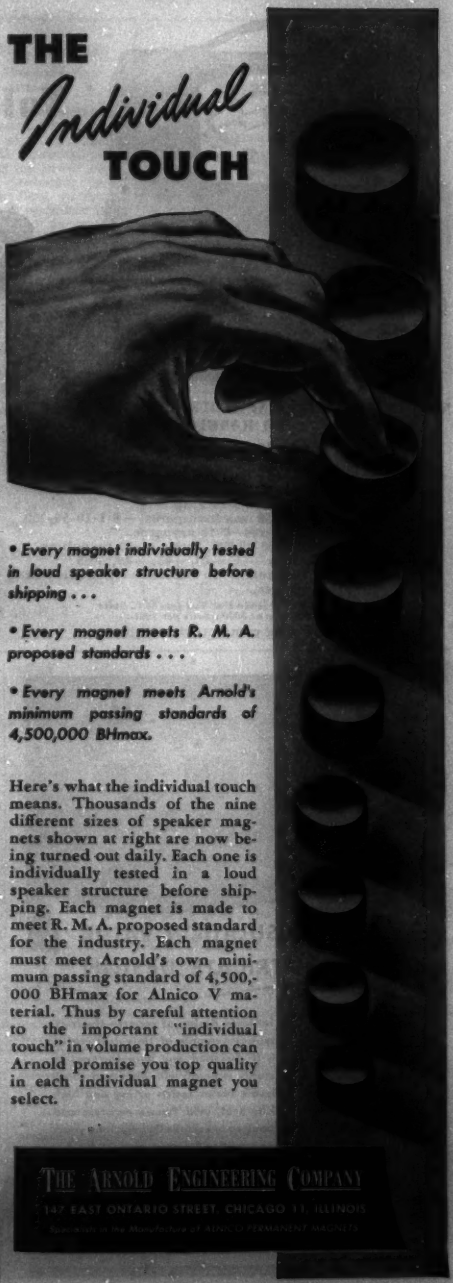

• *Every magnet individually tested in loud speaker structure before shipping . . .*

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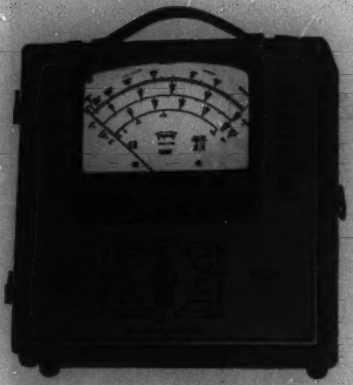

MODEL 2405

Volt·Ohm·Milliammeter

25,000 OHMS PER VOLT D.C.

TRIPLETT

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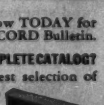

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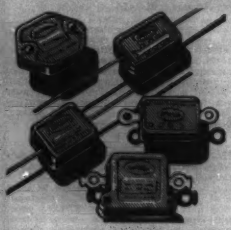

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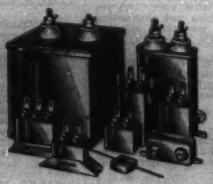

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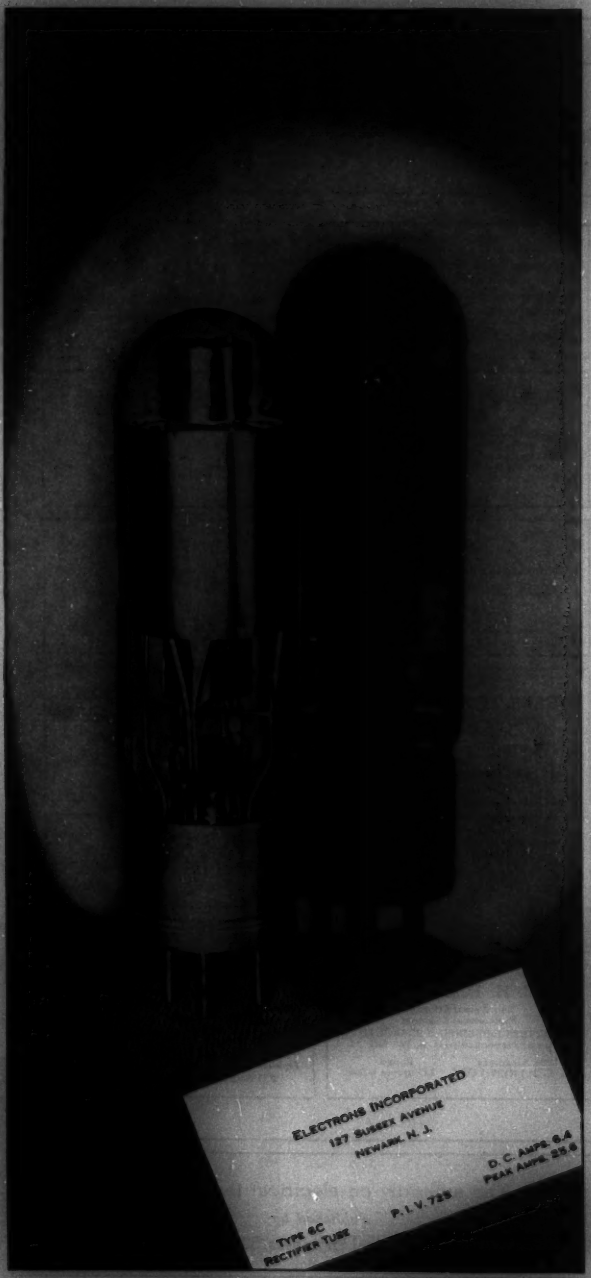

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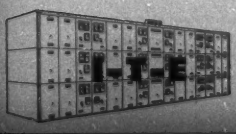

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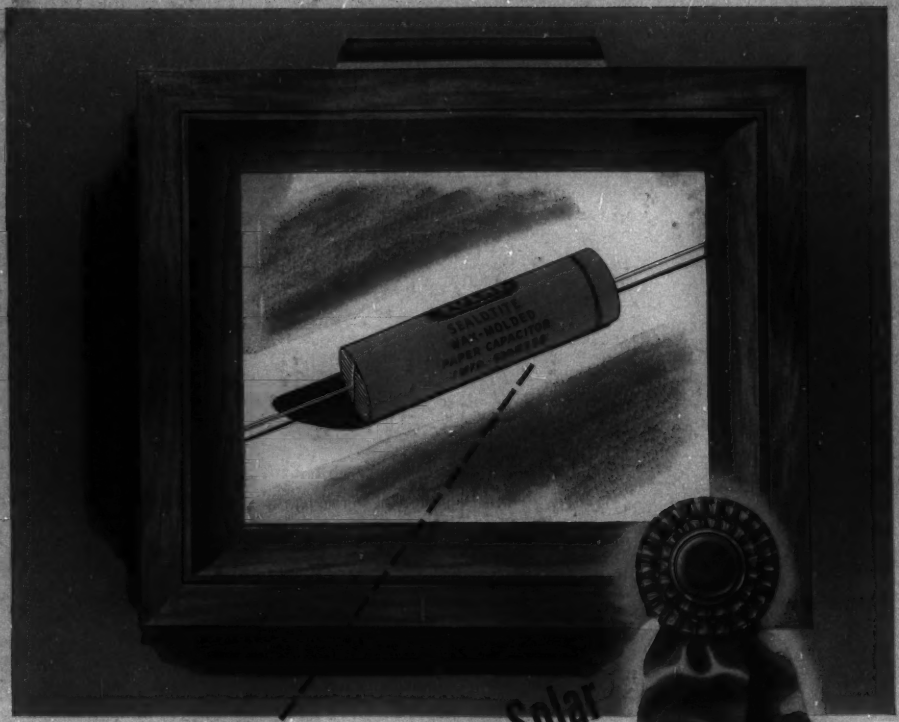

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